NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

GUIDEBOOK

55th Annual Meeting

October 4-6, 1963

Providence, Rhode Island

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G U I D E B O O K

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LEADERS:

Alonzo W. Quinn	- Professor of Geology, Brown University
Thomas A. Mutch	- Assistant Professor of Geology, Brown University
J. P. Schafer	- Geologist, U. S. Geological Survey
Sam L. Agron	- Professor of Geology, Rutgers University, Newark
William M. Chapple	- Instructor of Geology, Brown University
Tomas G. Feininger	- Graduate Student, Brown University, and Geologist, U. S. Geological Survey
Henry T. Hall	- Graduate Student, Brown University

Several members of the U. S. Geological Survey were most helpful in the preparation of this guidebook.

NEIGC MEETINGS, 1963, PROVIDENCE, RHODE ISLAND

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GUIDEBOOK - 55th Meeting

Providence, R. I., October 4-6, 1963

ERRATA:

- p. 4, line 33 - Maskechugg should be Maskerchugg.
- p. 17, line 13 - quarts should be quartz.
- p. 21, last line - east should be west.
- p. 24, line 12 - Bear sharp left should be sharp right.
- p. 31, Figure B-7a - arrows reversed.
- p. 38, first reference - Kay should be Kaye.
- p. 40, 6th line from bottom - the should be at.
- p. 42, 2nd reference - from should be iron.
- p. 47, 2nd line - Veavertail should be Beavertail.
- p. 49, line 1 - Conncecicut should be Connecticut.

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INTRODUCTION

Alonzo W. Quinn, Brown University

In planning the 1963 trips of the NEIGC the leaders decided that we should pick out those features of Rhode Island that are most different from those of other parts of New England. For that reason, the two bedrock trips on Saturday will be concerned with some aspects of the Narragansett Basin, a nearly unique major feature of New England geology. Likewise, the glacial trip of Saturday will provide an opportunity to study some glacial features in the vicinity of Point Judith that are somewhat different from the common glacial features of New England.

The Sunday trips will include a considerable variety of features, some of which are matched elsewhere in New England. However, some of these also are nearly unique in New England geology.

The Narragansett Basin occupies a place of considerable significance in southeastern New England geology. The significance lies partly in the fact that it is the largest mass of sedimentary rocks of known Pennsylvanian age in the New England area. Consequently, the character of these rocks provides the best evidence concerning the sedimentary and tectonic conditions prevailing in New England during the Pennsylvanian Period. In addition, these rocks were intensely deformed, and also metamorphosed, in the Appalachian orogeny, so that they provide evidence concerning that orogenetic episode. Still further, the plant fossils provide one of the few definite geologic ages in southeastern New England. Altogether, these rocks contain much evidence that can be used to elucidate the geologic history of this part of New England. Some of the evidence is known and has been interpreted; much is still obscure and the interpretations are yet to be made.

BRIEF VIEW OF RHODE ISLAND GEOLOGY

The Narragansett Basin rocks are the only rocks of known age in Rhode Island, but most of the other rocks can be given relative ages with respect to the Narragansett Basin rocks and to each other. Furthermore, most of the many different stratigraphic units can be gathered into several groups.

MAIN GROUPS OF ROCKS

These main groups are: (1) older(?) gneisses of north central Rhode Island, (2) the Blackstone Series of Precambrian(?) age, (3) the "Scituate Group" of central and southwestern Rhode Island, (4) the plutonic rocks of northeastern Rhode Island, (5) the Quincy granite and the East Greenwich Group of Mississippian(?) age, (6) the Pennsylvanian rocks of the Narragansett Basin, and (7) the Pennsylvanian or post-Pennsylvanian granitic rocks of southern Rhode Island.

Age Relations

Geological ages of the Rhode Island rocks have been assigned on the basis of evidence outlined below.

The rocks of the Narragansett Basin, group (6), seem rather definitely to be Pennsylvanian, on the basis of identification of plant fossils by older paleobatanists and by Knox in 1944.

The geological evidence for group (7) being Pennsylvanian or post-Pennsylvanian seems strong. The Narragansett Pier Granite intruded Pennsylvanian conglomerate and the Westerly Granite intruded the Narragansett Pier Granite. (Nichols GQ 91; Quinn, and others 1957)

The Mississippian(?) age of group (5) is based partly on the "giant conglomerate" in the Blue Hills area of Massachusetts, where boulders of the granite porphyry are contained in Pennsylvanian conglomerate of the Norfolk Basin. The evidence for the East Greenwich Group is not so clear-cut, but this group appears to be overlain unconformably by the Pennsylvanian rocks. Thus, in both places the Pennsylvanian rocks set an upper limit. The Quincy granite intruded the Esmond granite, and the Spencer Hill Volcanics of the East Greenwich Group contain boulders of the Esmond Granite. (Quinn GQ 17) The Esmond, when previously assigned to the Devonian, made a Mississippian age of group (5) almost necessary. However, this Devonian age is not now firmly established.

Group (4), plutonics of northeastern Rhode Island, seems, in part at least, to be younger than group (3) the "Scituate group". (Quinn GQ 13) However, there is no very good evidence of any large difference of age of the two groups; they may belong to the same general episode of granitic intrusion. The Esmond Granite, which is one of the youngest of both groups, is overlain unconformably by Pennsylvanian rocks at Natick, R. I. and it is older than the Quincy granite. It was also exposed to erosion before the formation of the pre-Pennsylvanian Spencer Hill Volcanics of East Greenwich. This all indicates that these plutonic rocks are at least two fairly long erosion intervals earlier than the Pennsylvanian rocks.

Definitely older than both plutonic groups, (3) and (4), is the Blackstone Series, group (2). This has been assigned a Precambrian(?) age, but the evidence is not strong. (Quinn, Ray, and Seymour GQ 1) They appear to be more metamorphosed than are the fossiliferous Cambrian rocks at Hoppin Hill in Massachusetts. The above history of the plutonic groups was preceded by the deposition and deformation of perhaps 20,000 feet of sediments and volcanics of the Blackstone Series. This suggests at latest a medial Paleozoic or an early Paleozoic age for the Blackstone Series; a Precambrian age is plausible.

Richmond (1952 - GQ 16) mapped a complex structure for the older(?) gneisses, group (1), and stated that they are unconformable beneath the Blackstone Series. The evidence is meager, but neither has any opposing evidence been discovered.

All of the above evidence is consistent with the following sequence of events: (I) older gneisses were formed and then deformed in an early orogeny, (II) Blackstone Series deposited, deformed, metamorphosed, and intruded by the two plutonic series (groups (3) and (4)), this orogeny being the Taconic or the Acadian, (III) erosion of older rocks and the formation of volcanics and plutonics of group (5), (IV) erosion of older rocks and deposition of Pennsylvanian rocks of the Narragansett Basin, and (V) deformation of Narragansett Basin rocks and intrusion of group (7), this being the Appalachian orogeny.

The few average ages based on radioactivity are:
Quinn and others, 1957; Hurley and others, 1960

Narragansett Pier and Westerly Granite	lead-alpha	234 M.Y.
	Rb-Sr	259 M Y.
	K-Ar	240 M.Y.
Metamorphic minerals of Pennsylvanian rocks	K-Ar	250 M.Y.
	Rb-Sr	260 M.Y.
Quincy Granite and Cowesett Granite	lead-alpha	270 M.Y.
Scituate group	lead-alpha	306 M.Y.

However, the ages by radioactivity as listed above, fitted into the recent time scales, imply a fast and furious pace of geologic activity around here; everything after the Blackstone Series happened during the Pennsylvanian and the Permian periods. It appears, therefore, that either (1) the geologic evidence is faulty or (2) the ages by radioactivity do not represent the time of origin of the rocks but rather something else, such as a later metamorphism or the time during cooling when the hot, loose, mineral lattices tightened up enough to start holding their argon or other radiogenic elements.

Older(?) Gneisses

Within the Georgiaville Quadrangle, Richmond (GQ 16) described three gneissic formations as being unconformable beneath the Blackstone Series. They include quartz-feldspar gneisses, a porphyroblastic biotite gneiss, and minor amphibolite. These are, from oldest to youngest, the Nipsachuck Gneiss, the Absalona Formation, and the Woonasquatucket Formation. The exposures near the supposed unconformity are sparse, so the age relationship is not firmly established. These gneissic rocks are layered and are of complex structure. They probably originated as feldspathic sedimentary rocks and as volcanics.

Blackstone Series

The Blackstone Series, exposed along the valley of the Blackstone River, includes the Mussey Brook Schist, the Westboro Quartzite, the Sneech Pond Schist, and the Hunting Hill Greenstone. (Quinn, Ray, Seymour, GQ 1) The most abundant lithologic types are quartz mica schist, quartzite, greenstone, amphibolite, and marble. Apparently it consisted of interbedded sedimentary and volcanic rocks, perhaps as much as 20,000 feet thick.

The several masses of Blackstone Series in the northern part of the state can be identified and correlated with some assurance. In the central and southwestern part of the state, however, many masses of metamorphic rocks are completely surrounded by igneous rocks and these are correlated only tentatively.

Several patches of meta-sedimentary and meta-volcanic rocks on the east side of the Basin and near the mouth of the bay are of unknown age, except that they are older than granitic rocks which in turn are older than the Pennsylvanian rocks.

Plutonic Rocks of Central and Southwest Rhode Island, "Scituate Group"

Much of central and southwest Rhode Island is underlain by large intrusives of gneissic rocks, chiefly quartz diorite gneiss, Scituate Granite Gneiss, Hope Valley Alaskite Gneiss, Ten Rod Granite Gneiss, and several unnamed gneisses.

(Quinn GQ 13, Moore GQ 105) These appear to be largely of syntectonic relations, as is indicated by their gneissic structure. They are intrusive into the Blackstone Series, and the Scituate granite gneiss has been intruded by the Esmond Granite.

These plutonic rocks appear to represent the late stages of an orogeny that deformed and metamorphosed the Blackstone Series. The earliest members of the series have well-developed foliation, whereas the latest members are more nearly massive. The mineral composition also varies in a common systematic way, from quartz diorite early to granite or alaskite late.

Plutonic Rocks of Northeastern Rhode Island

The main plutonic rocks of northeast Rhode Island are intrusive into the Blackstone Series and the Esmond Granite has intruded the Scituate Granite Gneiss. These include several quartz diorites, the Grant Mills Granodiorite, and the Esmond Granite. (GQ 1) They are moderately large discordant intrusives. These rocks generally are less foliated than are rocks of the Scituate Group. Therefore, the northeastern plutonic rocks probably represent a later stage in an orogenic cycle, possibly the same cycle, than does the Scituate Group.

The plutonic rocks on the east side of the bay and in the Newport vicinity bear no close similarity to anything on the west side and their ages are unknown except they are older than the Pennsylvanian rocks of the Narragansett Basin and younger than the schists of Tiverton, Sakonnet, and Newport. These include the Metacom Granite Gneiss of Bristol and Tiverton, granite exposed widely from Tiverton to Sakonnet Point, and coarse porphyritic granite of Newport and Conanicut Island. They may or may not be equivalent to some of the plutonic rocks on the west side of the bay.

Mississippian(?) Plutonic-Volcanic Series

In the northeast part of Rhode Island are several bodies of riebeckite-aegirite Quincy granite and an associated granite porphyry. These are rather small intrusive bodies. (GQ 1)

In central Rhode Island, just west of East Greenwich, is a mass of volcanic rocks and intrusive rocks, the East Greenwich Group. (GQ 17) These seem to have the same relations as has the Quincy Granite. Included here are the Spencer Hill Volcanics, the Maskechugg Granite, a granite porphyry, and the Cowesett Granite.

Pennsylvanian Rocks of Narragansett Basin

The Narragansett Basin is a complex synclinal mass of Pennsylvanian sedimentary rocks, perhaps as much as 12,000 feet thick. They are almost all clastic rocks of non-marine origin. Conglomerate, sandstone, arkose, graywacke, shale, and siltstone were the chief sedimentary rocks. In addition, there were numerous coal beds and very minor lenses of limestone. A few layers of felsite and also basalt are exposed in the northwestern part of the Narragansett Basin (in Massachusetts). Most of the Pennsylvanian rocks are gray to black, but the Wamsutta Formation in the northwest is red. All of these rocks are firmly indurated and those to the south are progressively metamorphosed.

The formations included are the Pondville Conglomerate, the Wamsutta Formation, the Rhode Island Formation, and the Dighton Conglomerate.

Two small outliers of probable Pennsylvanian rocks are the North Scituate Basin and the Woonsocket Basin, both about six miles west of the Narragansett Basin.

Pennsylvanian or Post-Pennsylvanian Rocks

Younger than the Pennsylvanian rocks of the Narragansett Basin are the Narragansett Pier Granite and the Westerly Granite. These both occur in the southern part of the state, the Narragansett Pier Granite chiefly as a large mass of medium-grained red granite and the Westerly chiefly as south-dipping dikes of fine-grained gray granite (G-1 Fairbairn and others 1951). The Bradford dike is about 65 feet thick, dips 28^{o} south, and extends for over a mile and a half. Many other dikes of the Westerly Granite are smaller and some are irregular in shape.

In addition to the above are several mafic dikes, some cutting the Westerly and some the Pennsylvanian rocks of the Narragansett Basin. A mass of gabbro in the west central part of the state appears to be unaffected by deformation, so it, too, may belong to the Pennsylvanian or post-Pennsylvanian group.

REFERENCES

This guidebook contains a list of general references and also more specific references for each trip. In addition, references to recent mapping are presented in the form of (a) an index map showing locations of quadrangles and (b) a list of quadrangle reports (mostly GQ maps) published and in preparation. These quadrangle reports resulted from a cooperative program between the U. S. Geological Survey and the R. I. Development Council (and its predecessor agencies).

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GEOLOGIC QUADRANGLE MAPS OF RHODE ISLAND

U. S. Geological Survey

in cooperation with Rhode Island Development Council

Published

U. S. Geol. Survey GQ No.	Date	Price	Bedrock	Surficial
1	1949	$0.50	Pawtucket	
2	1949	$0.50		Pawtucket
13	1951	$0.50	North Scituate	
16	1952	$1.00	Georgiaville	
17	1952	$1.00	East Greenwich	
22	1953	$1.00		Georgiaville
42	1954	$1.00	Bristol	
62	1955	$1.00		East Greenwich
70	1955	$1.00		Bristol
84	1956	$1.00		Providence
91	1956	$1.00	Narragansett Pier	
94	1956	$1.00		Crompton
105	1958	$1.00	Hope Valley	
106	1957	$1.00		Slocum
114	1959	$1.00	Slocum	
117	1959	$1.00	Carolina and Quonochontaug	
118	1959	$1.00	Providence	
136	1961	$1.00		Wickford
140	1961	$1.00		Narragansett Pier
No GQ Map, but similar map and text in U.S.G.S. Bull. 1071-1, 1960				Kingston
143	1961	$1.00		North Scituate
166	1962	$1.00		Hope Valley

Quadrangle Reports in Various Stages of Completion, July 1963

Bedrock	Surficial
Ashaway (R.I.-Conn.)	Ashaway
Chepachet	
Clayville	
Coventry Center	
Crompton	
Kingston	
Newport	
Oneco (R.I.-Conn.)	Oneco
Prudence Island	
Thompson (R.I.-Conn.)	Thompson
Tiverton	
Voluntown (R.I.-Conn.)	Voluntown
Watch Hill (R.I.-Conn.)	Watch Hill
Wickford	

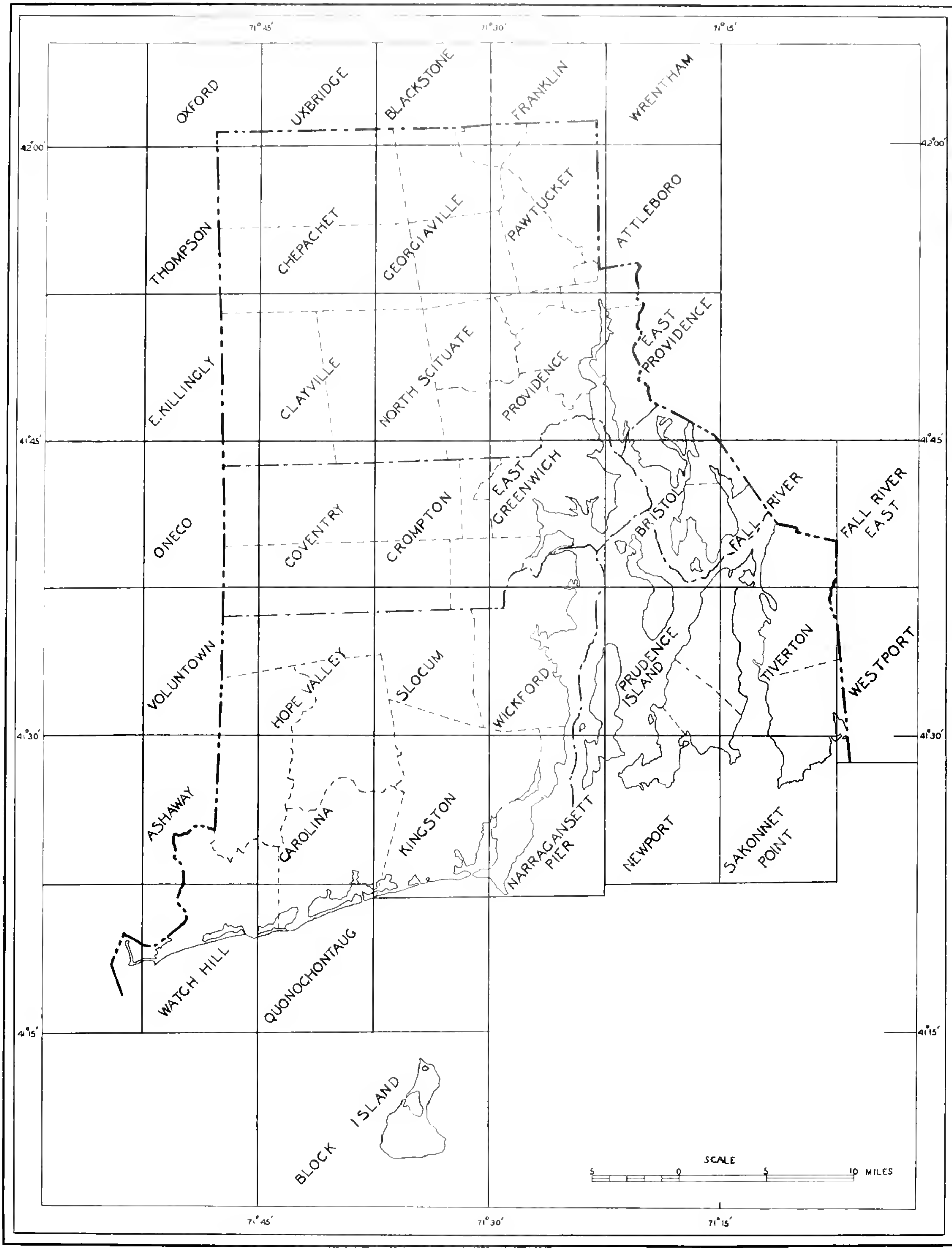
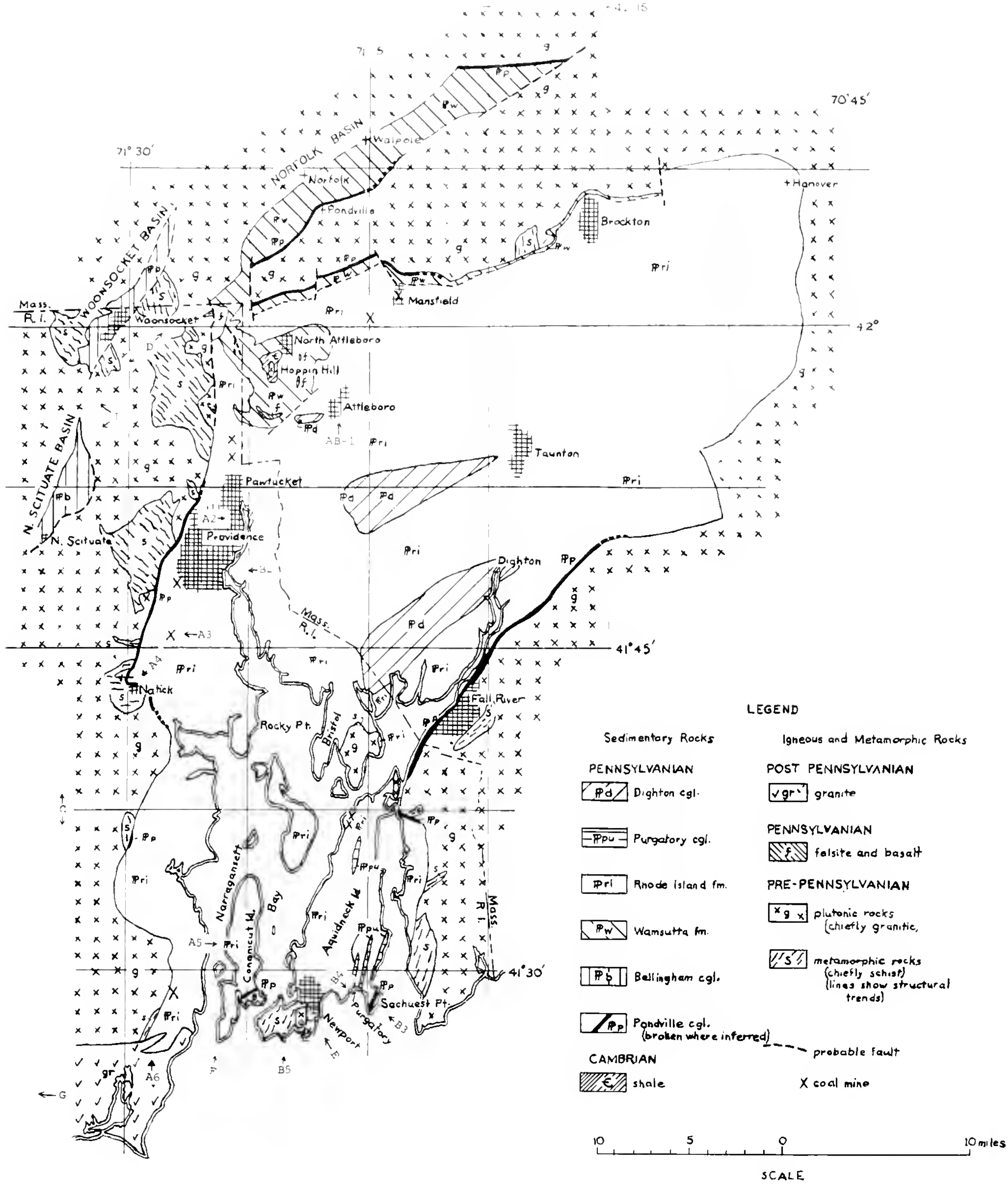


Figure 1

Index map of Rhode Island



GEOLOGIC MAP OF THE NARRAGANSETT BASIN
Modified from Quinn and Oliver, 1962
1963

Figure 2

Geologic map of Narragansett Basin; from Emerson, 1917, later published maps, and unpublished maps by G. E. Moore, Jr., L. J. Rusling, S. J. Pollock, G. H. Springer, and R. B. Williams.

A-2, B-2, etc. - stops or general locations of field trips.

PROGRESSIVE METAMORPHISM OF PENNSYLVANIAN ROCKS; RELATIONS TO OLDER AND TO YOUNGER ROCKS

Alonzo W. Quinn, Brown University

Itinerary

The main emphasis of Excursion A will be on progressive metamorphism of Pennsylvanian sedimentary rocks of the Narragansett Basin, but the localities visited will provide opportunity to observe such additional features as sedimentary structures of the Pennsylvanian rocks, unconformable relations of the underlying pre-Pennsylvanian rocks, and intrusive relations of Pennsylvanian or post-Pennsylvanian granitic rocks. The excursion will go from north to south along the western margin of the Narragansett Basin. Because of the expected size of crowds, only a few localities are suitable; several localities at intermediate positions in progressive metamorphism cannot be visited.

STOP 1 - Southern edge of Attleboro, Mass , just SW of Thacher St. crossing of N. Y., N. H., and H. Railroad, Attleboro Quadrangle.

This locality is most interesting for the sedimentary structures, channel fills, cross-bedding, etc. The rocks here probably should be assigned to the Rhode Island Formation, although some beds of red rocks like the Wamsutta Formation are exposed. Ides Hill, just west, is the smallest of the three synclines of Dighton Conglomerate, which is youngest of the Pennsylvanian formations here.

There may be difference of opinion about whether these rocks are metamorphosed. At any rate, these are about as low on the metamorphic scale as are any Narragansett Basin rocks. The clasts are chiefly quartz, feldspars, and lithic fragments, along with common accessory minerals. Micas are common, but they appear to be detrital. The clastic grains are sharp, randomly oriented, and apparently undeformed.

Log from Thacher St. locality:

Miles

00.0 West on Thacher St.
0.4 Rte. 123. Continue West on 123.
1.4 Under Rte. 95 (if this piece of Rte. 95 is open by October 5 we will go south on it, with consequent modification of road log).
3.7 Traffic light, left on 1A.
4.7 Right onto Rte. 95 (south).
6.0 Rhode Island State line; passing through Pawtucket, main center on right.
6.7 On left is road-cut in black shale and gray sandstone of Rhode Island Formation.
7.7 Crossing Blackstone River, rapids just upstream. Blackstone here has cut small rock gorge, having been diverted by ice block from former open valley. Acres of broken rock (R. I. Formation) from Rte. 95 excavation. Continue south to southeast on U.S. 1
9.2 Providence City line.
9.6 Right on Frost St. (Gaylord Diner on near right, Arena just ahead across street).

Miles

10.0 Left just before railroad bridge
10.2 Stop 2.

STOP 2 - Outcrop between N. Y., N. H., and H. tracks and North Burial Ground, Providence Quadrangle, GQ 118.

The rocks here are almost exclusively siltstone of the Rhode Island Formation. An early stage of metamorphism is marked by the presence of chlorite and white mica of undoubted metamorphic origin. (Quinn and Glass, 1958) Some of the white mica is paragonite. The clastic grains appear to have almost their original shapes, although some grains are broken and the edges of the grains are interfingered with white mica. Minerals identified in thin section are quartz, white mica, chlorite, and ilmenite, along with accessory zircon and tourmaline.

Continue South.

Miles

10.8 Left on Branch Ave.
11.1 Bear right on U.S. 1 (North Main St.).

On your right is the Rhode Island State Capitol, built of Georgia marble and completed in 1904. The marble dome was the first in the U.S. The three other large marble domes are: Minnesota capital, Taj Mahal, and St. Peter's

12.9 Follow U.S. 1
13.1 Right on U.S. 6 (W) to expressway.
14.9 On expressway, bear left on R.I. 2 (U.S. 6 goes right).
17.0 Bear right to Reservoir Ave., R.I. 2 & 3.
19.0 Garden City left at traffic light, south with Newport Creamery on right.
19.4 Stop 3.

STOP 3 - Vicinity of Cranston Mine, Providence Quadrangle, GQ 118

At the time of this writing the exposures around the mine had been covered and new excavations were being made east of the mine. It seems probable that adequate exposures will be accessible by October 5, 1963.

Sandstone, siltstone, and shale of the Rhode Island Formation are exposed near the mine, and the mine was in a bed of meta-anthracite. The clastic quartz grains are lens-shaped and interlocking, indicating considerable deformation. Biotite is a new metamorphic mineral here, the biotite isograd lying a short distance north. The shaly rocks have very prominent spangles of ilmenite, also a metamorphic mineral. Minerals seen in thin section include quartz, white mica, biotite, chlorite albite, ilmenite, zircon, and tourmaline. Garnet was not seen here, although it is present in the rocks about a mile and a half southwest. Paragonite was not detected here.

The Cranston Mine had a rather long period of activity. The first mining was as early as 1866 (Ashley, 1915). During part of 1887 250 to

300 tons of this coal was shipped to Pittsburgh, Pa., every week. Various mining companies worked this from time to time until about 1940 when Graphite Mines, Inc. took it over. They operated the mine until 1959, when they abandoned it. The earlier uses of material here were for fuel, some of it in the form of briquettes. Graphite Mines sold it as foundry graphite. The meta-anthracite bed is 20 feet thick over most of the mine area. It was 30 feet thick in a few places. The bed dips east about 20° to 25°. In 1948 the underground workings extended somewhat over 1200 feet north-south, along strike, and 400 feet down dip (Toenges and others, 1948).

Continue South.

Miles

19.6 Right on Sockanosset Cross Road.
19.7 Left on R.I. 2 & 3. Rhode Island State Institutions on left.
20.9 Looking ahead and to right you can see escarpment that marks margin of Narragansett Basin (escarpment a little over a mile away).
21.5 Bear right on road marked to Arctic and W. Warwick. Continue South on Providence St.
22.9 Right at corner, River St. on left, Wakefield Rd. on right, church on near right, Barber Vehicle Co. on far right.
23.3 Smaller groups commonly park near here and ascend hill to see rocks and relations of Stop 4.
23.4 Bear left, on Wakefield Rd. (Natick Ave. on right).
23.6 Left in private drive of Mr. Alexander Di Martino. Stop 4.

STOP 4 - Northwest of Natick, R. I., East Greenwich and Crompton quadrangles, GQ 17.

This is at the west margin of the Narragansett Basin. A few feet of the Rhode Island Formation lies on the Pondville Conglomerate and it, in turn, lies on the pre-Pennsylvanian Esmond Granite and an amphibolite of the Blackstone Series. Along most of the margin of the basin, the pre-Pennsylvanian rocks stand as an escarpment above the Pennsylvanian rocks. At Natick, however, the Pondville Conglomerate is as resistant as are the older rocks, so it forms the front of the escarpment.

The unconformity here is marked, not only by an angular discordance, but also by the fact that the conglomerate contains a few boulders of Esmond Granite, which is here intrusive into the Blackstone Series.

The Pondville Conglomerate is variable and contains many large and angular boulders. Most of the boulders are quartzite, probably derived from the Westboro Quartzite which is exposed a few hundred feet to the south. The bedding is unusually variable and irregular.

Metamorphic intensity here was enough to cause the formation of garnet. Some of these are megascopically visible, but very irregularly distributed. Some of the boulders are considerably elongated.

The marginal contact here is offset by a small fault.

Back to corner of Barber Vehicle Co.

Miles

24.4 On River St.
24.6 Left on East Ave.
24.9 Traffic light, cross Rts. 2 & 3, Bald Hill Rd. Continue on East Ave.
27.4 Left on Rte. 5, Greenwich Ave. sign to State Airport.
27.6 Right on Main Ave. sign State Airport.
28.5 U.S. 1

We will go straight and then left to State Airport for lunch. This superfluous non-geological diversion will not be included in road log.

After Lunch.

28.5 Greenwood, intersection Main Ave., U.S. 1 (Post Rd.). South on U.S. 1
32.4-33.0 East Greenwich. The road here is almost on the margin of the Narragansett Basin, as volcanic and intrusive rocks of the Mississippian(?) East Greenwich Group are exposed on the escarpment just west of the road.
36.8 Quonset Naval Air Station and Construction Battalion on left; "Devil's Foot" ledge on right; some of the sandstone in this vicinity contains amphibole, formed here as a metamorphic mineral.
39.0 Left on U.S. 1A.
39.6 Wickford
39.8 View of Wickford Harbor
43.0 Left toward Jamestown Bridge, Rte. 138. Large road cut in sandstone and shale of Rhode Island Formation. Feldspathic sandstone has metamorphosed to a granite-looking rock.
43.6 Toll house - 60¢ for private cars. Cross Jamestown Bridge (1940, 6982' long, 135' clearance).
45.0 Jamestown, Conanicut Island

STOP 5 - West shore of Conanicut Island, about 300 feet north of east end of Jamestown Bridge, Wickford quadrangle. Walk down (W) to shore along north side of bridge, and then north across mouth of brook. Conglomerate, sandstone, and shale of Rhode Island Formation metamorphosed to stretched-pebble conglomerate, feldspathic quartzite or gneiss, and garnet-staurolite schist. Simple structure, with moderate dip to east. Cross-bedding well shown in places. Almost 2000 feet south on shore, recognizable fern fossils have been found between beds of garnet-staurolite schist. Hurley and others (1960) got a K-Ar age of 250 ± 12 m.y. and a Rb-Sr age of 260 ± 16 m.y. on the biotite here.

45.0 Back across bridge.
46.5 Toll house again.
47.1 Left on Rte. 1A and Rte. 138.
48.5 Saunderstown
49.9 Continue S on Rte. 1A (Rte. 138 goes right).
51.6 To east is Bonnet Pt.; pegmatite intrusive into Pennsylvanian shale and sandstone; pegmatite is visible from here as sea stack. Many large pegmatites are exposed along the shore south of Bonnet Shores.

Miles

53.6 Narragansett Pier Granite exposed on right. This is the Pennsylvanian or post-Pennsylvanian granite from which the pegmatites at Bonnet Point and elsewhere were derived.

54.5 Narragansett, right on Rte. 1A.

55.8 Rotary

55.9 Right; follow sign to Providence.

56.2 STOP 6 - South end Tower Hill, Narragansett Pier quadrangle, GQ 91. Walk east down hill to back (north bank) of gravel pit. Here conglomerate and schist of the Rhode Island Formation are cut by sills and other intrusives of the Narragansett Pier Granite and by related pegmatite. A lead-alpha age is 235 m.y. Some of the granite stringers are tightly folded, indicating syntectonic intrusion. The pebbles show extreme elongation (13:1 according to Nichols GQ 91). Muscovite, biotite, garnet, and ilmenite are the main metamorphic minerals. Sillimanite was not detected here, although it has been identified in Pennsylvanian rocks at Wakefield, a little more than a mile west. The quartz grains are interlocking and very much strained.

56.2 Return to Providence.

The following brief notes apply to a return by Rtes. 1, 2, 3, but traffic and other conditions might make another route preferable.

59.0-60.2 Exposures of Hope Valley Alaskite Gneiss, part of Scituate group. Lead-alpha age 303 m.y.

60.4 Rte. 138 goes west 4 miles to University of Rhode Island campus at Kingston.

61.3 Pennsylvanian rocks near margin of Narragansett Basin exposed in woods 600' east.

61.9 Hope Valley Alaskite Gneiss exposed.

62.6 Margin of Narragansett Basin comes through somewhere near here.

68.5 Pondville Conglomerate in woods 600' west of road.

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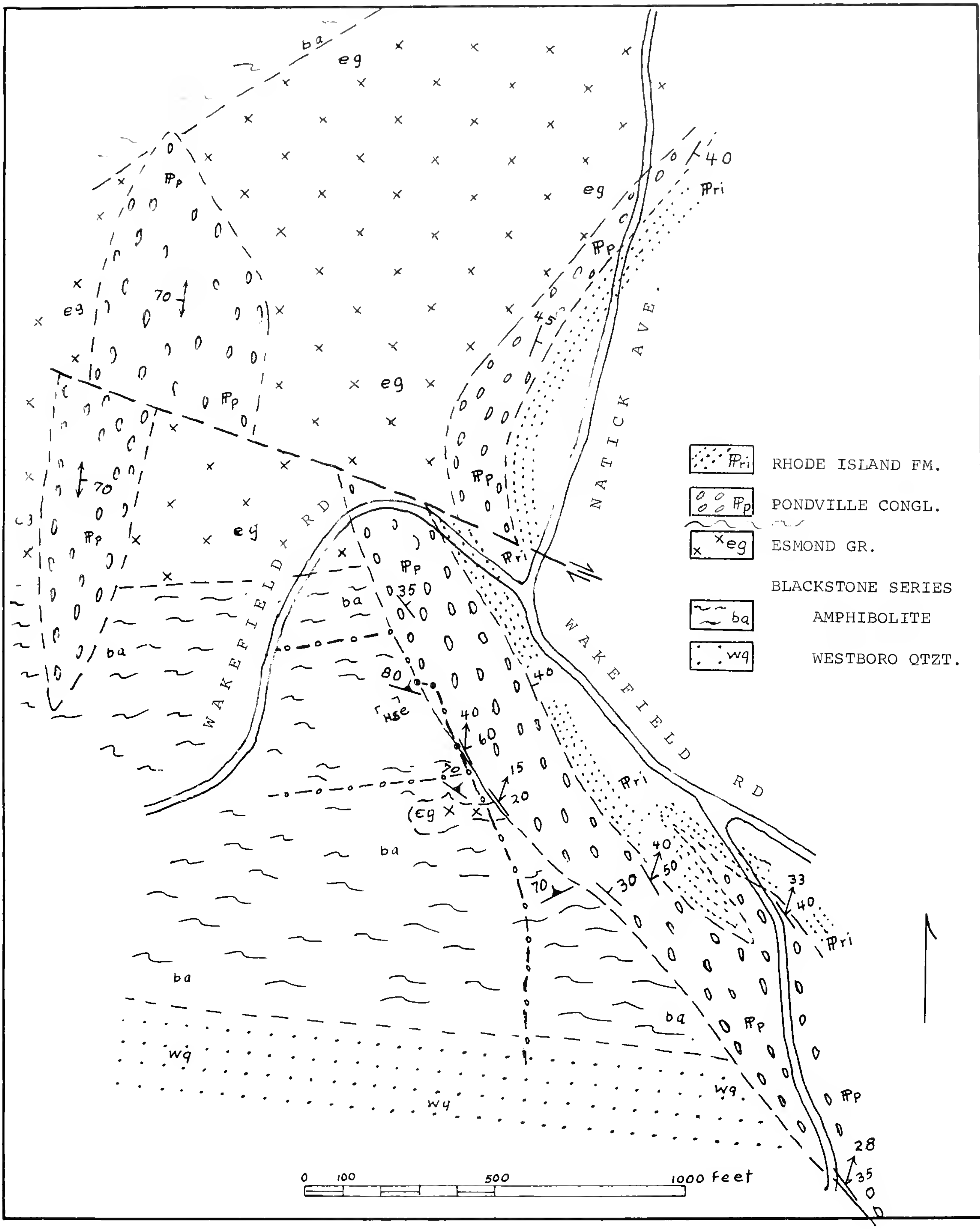

Figure A-1 - GEOLOGIC MAP OF NATICK AREA

SUPPLEMENTARY NOTE TO TRIP B

Because of an unusually dry summer certain exposures generally covered by water are now accessible. For this reason it has been decided to add one stop to Trip B. This stop will precede all others and is called STOP 0.

STOP 0 - From intersection of Rtes. 123 and 1 proceed north three miles along Rte. 1. Turn left (west) on Hoppin Hill Ave. and proceed .25 mile to point where road crosses reservoir. Exposures are on north side of road.

This is locality 1 mentioned by Shaler, Woodworth & Foerste (1899, p. 386). Along the west side of the reservoir are exposures of granite. In the middle of the reservoir are several knobs underlain by reddish and gray siltstone and shale interbedded with thin, irregular silty limestone layers several inches thick. On the eastern side of the reservoir in the woods there are exposures of coarse conglomerate containing quartzite pebbles.

The limestone layers contain abundant *Hyolithes*. Collections from here and several nearby localities have also yielded a number of trilobites including *Strenuella* and *Salterella*. The fauna was first recognized as early Cambrian by Shaler (1888). The fossils were re-examined by Shaw (1950) who correlated them with the *Obolella* zone.

The character of the contact between the granite and Cambrian rocks was disputed for many years. Dowse (1950) describes an actual exposure of a sedimentary contact between basal Cambrian beds and coarse-grained granite, establishing this rock as Precambrian.

Conglomerates on the east side of the reservoir are included in the basal Pennsylvanian. Although Wamsutta rocks outcropping nearby are strikingly similar to the Hoppin Hill Cambrian beds, an Allegheny flora clearly establishes their younger age.

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TRIP B

SEDIMENTARY AND STRUCTURAL HISTORY OF NARRAGANSETT BASIN

Thomas A. Mutch, Brown University

Stop 4 by

Sam L. Agron, Rutgers University, Newark

General Discussion

During this trip sedimentary and structural features of Pennsylvanian nonmarine rocks within the Narragansett Basin will be observed. As shown in Figure 2 this is a synclinal basin approximately 60 miles long and 20 miles wide, trending north and northeast. Pre-Pennsylvanian sedimentary rocks will be seen near Newport on Aquidneck Island along the southern margin of the basin.

Throughout most of the Narragansett Basin the Pennsylvanian overlies with angular unconformity metamorphic and plutonic rocks. On the western margin the Precambrian(?) Blackstone Series, made up chiefly of quartz-mica schist and quartzite, is intruded by Devonian(?) and Mississippian(?) rocks ranging from quartz diorite to granite. Most of the northern and eastern part of the basin is underlain by the Dedham granodiorite of Precambrian or Paleozoic age. At the southern extremity sedimentary and volcanic rocks of uncertain age are well displayed directly below the Pennsylvanian.

The Pennsylvanian rocks were first described in detail by Shaler, Woodworth and Foerste (1899). A recent and comprehensive discussion of the stratigraphy is provided by Quinn and Oliver (1962). Four formations are commonly recognized: decreasing in age these are Pondville Conglomerate, Wamsutta Formation, Rhode Island Formation, and Dighton Conglomerate. A conglomerate on Aquidneck Island, the Purgatory Conglomerate, is sometimes correlated with the Dighton although it occurs much lower stratigraphically in the Pennsylvanian section.

The Pondville Conglomerate was named by Shaler, Woodworth and Foerste (1899, p. 135-136) for exposures of arkose and quartz pebble conglomerate near Pondville, Massachusetts, in the Norfolk Basin. According to them this zone of arkose extends in discontinuous crops for fifteen miles along the northwestern margin of the basin. Several exposures of fluvial conglomerate along the western margin have been assigned to this formation, but the unit is not present in very limited exposures of rocks along the northern and northeastern margins. Basal units along the southeastern and southern border of the basin are well displayed and, although they are strikingly different from rocks along the western margin, they have been included in the same formation. This southern sequence comprises shale, siltstone and sandstone composed of varying amounts of dark quartz, partially altered feldspar, muscovite metamorphically generated from clay minerals, and carbonaceous material. The quartz commonly is of granule size but coarser-grained conglomerate is lacking.

The Wamsutta Formation includes a sequence of siltstone, sandstone, and conglomerate characterized by reddish color and restricted to the northwestern part of the basin. In the Attleboro area there are two layers of basalt and a single layer of rhyolite. Recent work by Eckelmann and Woods (1961) demonstrated that the rhyolite is extrusive, and the basalt may well have a similar origin. The fine-grained rocks of the Wamsutta Formation display ripple marks, mud cracks, curled mud chips and organic reworking. Detrital volcanic material

is abundant in many of the sandstones. Some of the conglomerates are poorly sorted with angular felsite blocks up to several feet in diameter in a silt matrix, suggesting a mud flow origin. Interlayered with these rocks are beds of well-sorted quartz-rich sandstones, apparently fluvial channel sands. The red color of the Wamsutta is partly the consequence of fine-grained interstitial iron oxide pigment and partly the result of large amounts of pink felsite detritus.

The Rhode Island Formation with a stratigraphic thickness of approximately 10,000 feet is the most extensive unit within the Narragansett Basin. Exposed rocks are principally fluvially deposited sandstone and conglomerate with minor amounts of siltstone. An extensive glacial cover is pierced only by topographic highs under-lain by resistant coarse-grained rocks, so shale and siltstone may be more abundant than surface exposures suggest. Fine-grained rocks are apparently more common in the southern part of the basin but this may be a reflection of more complete exposure in shore line cliffs. Rhode Island Formation sandstones are light gray graywackes with quartz, feldspar, mica, and lithic fragments in a clay matrix. Boulders in the conglomerates are chiefly quartzites and granites. Primary structural features are not common but some sandstones contain current cross-bedding. Several coal horizons occur in the lower part of the formation.

The Dighton Conglomerate overlies the Rhode Island Formation and is exposed in three synclinal areas in the northern part of the basin. Although this unit is not composed exclusively of coarse-grained rocks, it contains thick lenses of conglomerate not present in underlying rocks. The general appearance of individual samples is similar to that of the Rhode Island Formation.

The assignment of rocks within the Narragansett Basin to the Pennsylvanian is on the basis of fossil plants. There have been no recent comprehensive descriptions of the flora but Knox (1944) classified a Wamsutta assemblage as early Allegheny. While Pennsylvanian fossils are common in both the Wamsutta and Rhode Island Formations, no plants have been described from the Dighton Conglomerate. This raises the possibility that it is post-Pennsylvanian, although there is no positive evidence supporting this view.

The distribution and character of sedimentary rocks within the basin suggests that the principal direction of sediment transport was north to south. Currents flowing from northeast to southwest are indicated by current cross-bedding and plant alignment at a number of localities within the Rhode Island Formation (Towe, 1959). Along the western margin basal conglomerates and sandstones rest on plutonic and metamorphic rocks which show no development of a pre-Pennsylvanian weathering profile. The mineral constituents of the sedimentary rock correspond in large part to those of immediately adjacent older rocks, indicating local transport of mechanically weathered detritus in a region of active erosion and sedimentation. Along the southeastern margin of the basin the underlying plutonic rocks are deeply weathered and the clay, quartz and partially altered feldspar in basal Pennsylvanian sediments is derived locally from this weathered zone. In contrast to these two areas just described, basal fine-grained well-sorted sandstones in the northern part of the basin have heavy mineral suites unlike those of local pre-Pennsylvanian rocks, indicating that detritus was not derived from a nearby source.

This variation within basal Pennsylvanian rocks indicates a highland to the west and a deeply weathered stable lowland to the east and south. Mature well-sorted sediments in the north were deposited in a flood plain probably associated with the major drainage system leading into the basin.

Problems regarding the source of quartzite boulders common in both the Dighton and Purgatory Conglomerates are raised by fossils which they contain. Walcott (1898) identified several species of Obolus which are confined to Lower Ordovician rocks of Great Belle Island, Newfoundland. More recently Howell (personal communication, 1962) has examined a number of boulders from a collection made some years ago. The specimens are simply labeled "Newport, R.I.", and presumably came from the Purgatory Conglomerate outcropping there although they could be from glacial drift. Howell identified several species of Lingulella characteristic of Upper Cambrian rocks in eastern New York State. He did not observe any specimens of Obolus.

Following their deposition Pennsylvanian rocks were folded and subjected to variable metamorphism. Folds in the northern part of the basin are broad and simple while the compression in the southern part of the basin is much more extreme. Folds here are locally overturned and axial plane cleavage is well developed. This intense compression was accompanied by stretching of pebbles within the Purgatory Conglomerate, a feature not seen in the Dighton Conglomerate in the northern part of the basin.

An increase in intensity of metamorphism toward the south within the Narragansett Basin is very apparent along the western side. This progression is not so marked along the eastern side where there is development of biotite, but not garnet or staurolite.

TRIP B

ITINERARY

STOP B-1 - Southern edge of Attleboro, Mass., just SW of Thacher St. crossing of N.Y., N.H., and H. Railroad, Attleboro quadrangle.

STOP 1 - Rhode Island Formation. Vertical beds show a number of features indicating a fluvial environment of deposition. These include sandstone and conglomerate lenses, cross-bedding, and channeling contemporaneous with deposition. (See Figure B-2). Mottled sandstones and siltstones in the lower part of the section are probably the result of reworking by burrowing animals. The outcrop is polished and striated by glacial action; rocks outcropping 20 yards to the south show the effects of stream erosion related to the glaciation.

Log from Thacher St. locality:

Miles	
0.0	East on Thacher St.
0.5	Turn right (south) on Rte. 152.
8.3	Turn right (south) on Rte. 1A at stop sign.
8.8	Bear right on Rte. 1A.
9.8	Proceed straight through stop light on Rte. 114.
10.2	Proceed straight through stop light on Rte. 114.
10.6	Turn left (east) at stop light on Rte. 6 (Warren Ave.).
11.1	Stop B-2. East Providence quadrangle. To reach outcrop walk 100 yards south, crossing road just south of Rte. 6. Watch out for traffic.

STOP B-2 - A typical exposure of the Rhode Island Formation. Flat-lying beds of sandstone contain discontinuous conglomerate horizons. Plant fragments are abundant along bedding planes. These tend to be oriented in a northeast-southwest direction. (See Figure B-3). A similar alignment of plant fragments and dip directions of cross-beds at other localities within this formation suggest currents flowing from the northeast. (Towe, 1959).

11.1	Proceed east on Rte. 6.
11.5	Bear right on Rte. 6.
16.6	Turn right (south) at stop light on Rte. 136.
18.6	Rhode Island Formation exposed on right (west) side of road. Well developed foliation striking N 40 W and dipping 25 NE obscures the bedding which is nearly horizontal.
19.2	Bear left on Rte. 136, following Newport-Bristol sign.
19.5	Bear right on Rte. 136.
19.6	Proceed straight through stop light on Rte. 136.
23.7	Exposures of Metacom granite gneiss on left (east) side of road. This unit has been interpreted as pre-Pennsylvanian metasediments. (GQ 42) Pennsylvanian rocks crop out several miles north and west of this point but the contact with the Metacom gneiss is not exposed.
25.9	Proceed south across Mt. Hope Bridge to Aquidneck Island (Rhode Island). Excellent view of Narragansett Bay from top of bridge.

Miles

25.9 Prudence Island and west shore of bay to the right, east shore of the bay to the left. Topographic rise less than a mile behind shore on the left marks contact between pre-Pennsylvanian plutonic rocks and less resistant Pennsylvanian rocks.
26.7 Bear right on Rte. 114.
28.1 Proceed straight through stop light.
29.1 Bear right on Rte. 138 at light.
29.9 Bear left on Rte. 138.
30.0 Good view across southern inlet in Narragansett Bay (Sakonnet River) towards Little Compton, R.I.
30.5 Rhode Island Formation exposed on right (west) side of road behind buildings.
32.8 Turn left (east) on Sandy Point Road.
33.3 Turn right (south) on Wapping Road.
35.3 Turn left (east) on Old Mill Lane. Stretched pebble conglomerate is exposed on northeast corner of intersection.
36.1 Turn right (south) on Indian Ave.
37.0 On right and visible from bus are sarcophagus and effigy of Raphael Pumpelly (1837-1923; explored Gobi and Siberia 1863, "Across America and Asia", 1870; Harvard prof. 1866-73; State Geol. Mich. 1869-71, Mo. 1871-73; pres. GSA 1905; published on Mich Cu., Green Mts., mining indust., census, etc.).
38.0 Continue straight on Indian Ave. at intersection.
39.6 "Hanging Rock", large cliff of steeply dipping Pennsylvanian conglomerate on right (west) side of road.
39.7 Turn left (east) along shore road.
40.8 Entrance to U.S. Naval Rifle Range. Entrance without a pass is not permitted. Passes can be obtained at Newport Naval Gate 1. Stop B-3 is located close to southern tip of Sachuest Point within firing range. Sakonnet Point Quadrangle.

STOP B-3 - This series of outcrops clearly shows the difference between Pennsylvanian and pre-Pennsylvanian rocks with respect both to original sedimentary character and to style of structural deformation. The geology is shown in Figure B-4.

Pennsylvanian beds overlie older beds with angular unconformity. Rocks are coarse-grained sandstones made up of quartz granules and fine-grained muscovite interbedded with black shales. Basal beds contain detrital feldspar phenocrysts and large fragments of underlying rocks. Pre-Pennsylvanian rocks are poorly sorted siltstones, sandstones, and conglomerates with lenticular bedding, cross-bedding and, locally, graded bedding. Many of the angular boulders in conglomerates are derived from volcanic rocks. Quartzite boulders are extremely rare and boulders of plutonic rocks are not common.

Cross-bedding indicates that pre-Pennsylvanian rocks along the southern part of the point are overturned, dipping to the southeast. As the shoreline is followed north beds become upright, dipping to the northwest. A prominent joint system strikes N10E with movement of several inches along many of the surfaces. Pennsylvanian rocks are tightly folded and faulted, and cleavage is well developed in shales. Faults are accompanied by large quartz veins, especially in the northern part of the point.

40.8 Proceed west on shore road.
42.2 Stop B-4; includes exposures directly east of parking area and south of shore road as well as extensive cliffs extending south from ~~east~~ end of beach. Newport quadrangle.
west

STOP B4

PURGATORY

Sam L. Agron

Stop B4. About 1¼ miles east of Newport, at the northeast corner of the triangular peninsula whose southern terminus is Easton Point. A composite cross-section of the peninsula (Fig. B5.b) gives some idea of the variable clastic lithology of the Pennsylvanian Rhode Island Formation. Rapid facies changes, pinching, lensing, and interfingering of the conglomerate, schistose sandstones and graywackes, and black slaty beds are common. The major structure of the peninsula is anticlinal, upon which are smaller warps and drag folds, some with vertical to overturned limbs. The extraordinary elongated boulders that appear at numerous places will be inspected along the shoreline north of Purgatory chasm. The boulders range in length from several inches to over four feet (one is 13 feet long). They are mostly quartzite, some containing considerable mica and feldspar; a few are granite and a few are felsite.

In the coarser beds the boulders lie tightly packed; little matrix material is present. They are elongated about N10°E, parallel to the fold axes (b) and a lineation which appears as a faint striation on thin coatings of micaceous material (muscovite and chlorite). This lineation may be seen at the south end of the east side of the isolated outcrop several hundred feet along the beach to the northeast of the main exposure (Location 1, Fig. B5a).

Several thin, dark gray sandy beds indicate bedding dips about 60° to the east. The flat (ab) plane of the triaxial boulders does not lie in the bedding plane, but generally follows a foliation or a cleavage direction which strikes parallel to bedding but dips gentler or steeper in different parts of the structure (Fig. B6). At this stop (Location 1) the plane dips about 60° to the west. Although the boulders show their long axes consistently oriented north-south and horizontal, the flat a-b planes are less uniformly parallel, except where shearing in the a-b plane was very marked.

The tendency of the flat surfaces of the elongated boulders not to be parallel to bedding suggests that the boulders may have been rotated individually about b during folding and also sheared along cleavage planes inclined to bedding. Evidence for such movements occurs in the area.

The axial ratios (b:a:c) of the boulders average approximately 4.1:1.5: 1. Where shearing was more intense it may be 5.7:2.4: 1. The tapered ends commonly consist of intensely crushed material. Some boulders show an elongated rhombic or polygonal outline, in which the straight sides lie along cleavage and shear directions (Fig. B7). Many boulders show indentations or pinching where they were appressed against adjacent boulders; the compressive stress acting east-west but not necessarily horizontally.

One or more sets of fractures may be present in the boulders. Some of these are regional joints transecting many feet of the country rock, but others are small fractures limited to the boulders. Transverse (ac) joints are abundant. They are steep to vertical and trend east-west, essentially perpendicular to the fold axes. These are tension joints; many show a north-south separation. Some are occupied by quartz veins (Fig. B7e). Purgatory chasm has resulted from wave surge and erosion along a prominent cross-joint striking perpendicular to the shore.

Longitudinal fractures (Fig. B7C) may represent a foliation or a cleavage direction, or possibly the original bedding within the boulder. It may be emphasized that faint streaks, apparently bedding, are oriented transversely in some quartzite boulders and yet have not opened up as tension fractures.

Oblique shear fractures striking NE-SW and NW-SE may appear as a single set or as a conjugate system. Slip commonly appears along these joints as a series of stepped offsets producing extension along the major axis, b (Fig. B8). Some oblique fractures, striking at an obtuse angle to b, have opened up because of post-fracturing extension along b (Fig. B7D).

Quartz veins, from one-eighth of an inch to more than a foot thick, follow the several joint directions.

Transverse veins occupying tension fractures tend to be wider than the other sets. Several groups of short en-echelon veins on the flanks of folds, showing an E-W strike of the individual veins, indicate E-W compression and N-S extension. The quartz veins are penetrated by joints and cleavage of the host rock, indicating their syntectonic age. This is also indicated by the folded, contorted, and sheared appearance of some veins. Under the microscope the vein quartz shows strong strain shadows and Boehm lamellae.

Magnetite grains are abundant in some of the sandier beds especially along the western side of the outcrop (Fig. B9). They appear in whisps and layers up to one inch thick, as well as in scattered grains following certain beds.

Miles

42.2 STOP B4 - Proceed west on shore road, bearing left and going up hill.
42.3 Turn right (west) on unmarked road.
42.5 Entrance to St. George's School. Lunch at St. George's School, through the courtesy of Headmaster, Mr. Archer Harman, Jr. and Mr. Lawrence Goldthwait; on the lawn if we have a fine Rhode Island day, in new science building if we have poor NEIGC weather.
43.3 Bear left on Memorial Blvd.
44.7 Turn left (south) on Bellevue Ave. Most mansions along this avenue and Ocean Drive were built during 1890-1910 to serve as summer cottages. See Figure E-1 Field Trip E for a description of some of these houses.
47.7 ~~Bear~~ sharp ~~left~~ right and follow Ocean Avenue.
50.9 Stop B-5. 100 yards east of Brenton Pt. and just east of intersection of Ocean Ave. and Atlantic Ave. Exposures are along shore line south of sea-wall.

STOP B-5 - Pre-Pennsylvanian sedimentary rocks are deformed and metamorphosed but still show original sedimentary features. Prominent foliation surfaces are undulating, striking E-W and ranging in dip between 5^oS and 15^oN. Sedimentary beds strike SE and dip from 35-50 N. Prominent joints with movement along some surfaces trend slightly east of north. A basic dike was intruded along one of these fractures and has itself been faulted, sheared, and plastically deformed. Sedimentary rocks now contain a quartz-muscovite-chlorite metamorphic assemblage.

Graded bedding within sandstones and siltstones is well developed and consistently shows tops to the north. Several of the thicker graded beds near the southern part of the joint show internal folding and included fragments of underlying rocks.

Geology at Stop B-5 is shown in Figure B-10.

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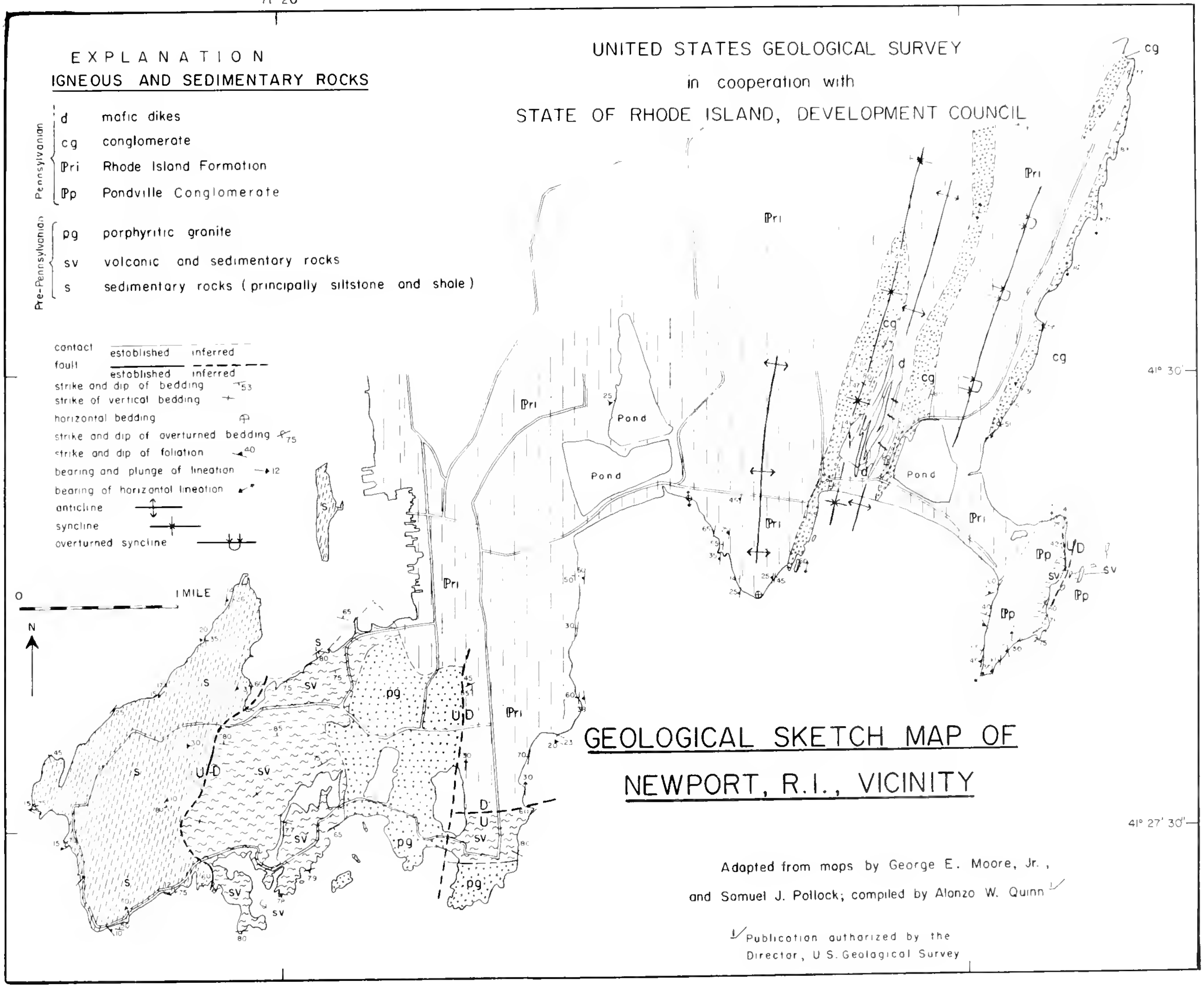

UNITED STATES GEOLOGICAL SURVEY
in cooperation with
STATE OF RHODE ISLAND, DEVELOPMENT COUNCIL
GEOLOGICAL SKETCH MAP OF
NEWPORT, R.I., VICINITY
Adapted from maps by George E. Moore, Jr., and Samuel J. Pollock; compiled by Alonzo W. Quinn 1/
1/ Publication authorized by the Director, U.S. Geological Survey
EXPLANATION
IGNEOUS AND SEDIMENTARY ROCKS
Pennsylvanian
d mafic dikes
cg conglomerate
IPri Rhode Island Formation
IPp Pondville Conglomerate
Pre-Pennsylvanian
pg porphyritic granite
sv volcanic and sedimentary rocks
s sedimentary rocks (principally siltstone and shale)
contact established inferred
fault established inferred
strike and dip of bedding
strike of vertical bedding
horizontal bedding
strike and dip of overturned bedding
strike and dip of foliation
bearing and plunge of lineation
bearing of horizontal lineation
anticline
syncline
overturned syncline
0 1 MILE
N
71°20'
71°15'
41°30'
41°27'30"
Pond
Pond
Pond
IPri
IPp
cg
d
pg
sv
s
U D

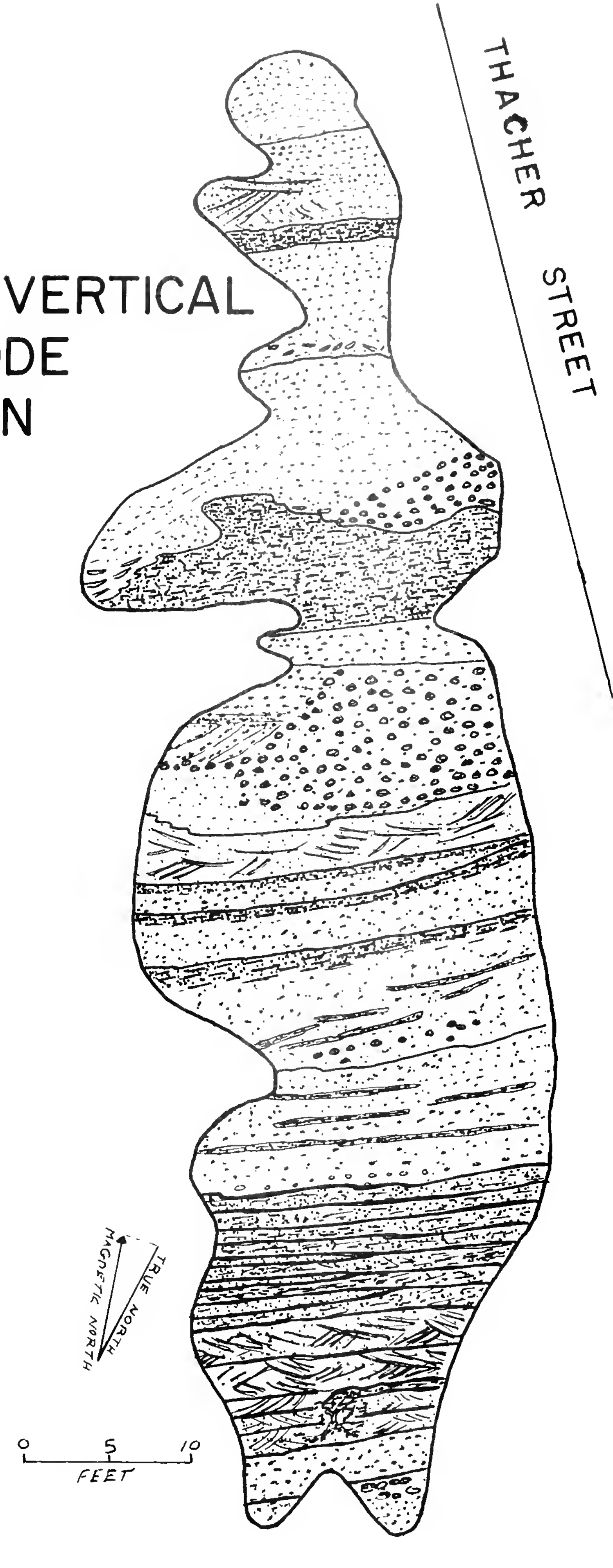
FIGURE B-2

SKETCH MAP OF VERTICAL BEDS WITHIN RHODE ISLAND FORMATION AT STOP B-1.

Conglomerate

Gray sandstone

Reddish siltstone



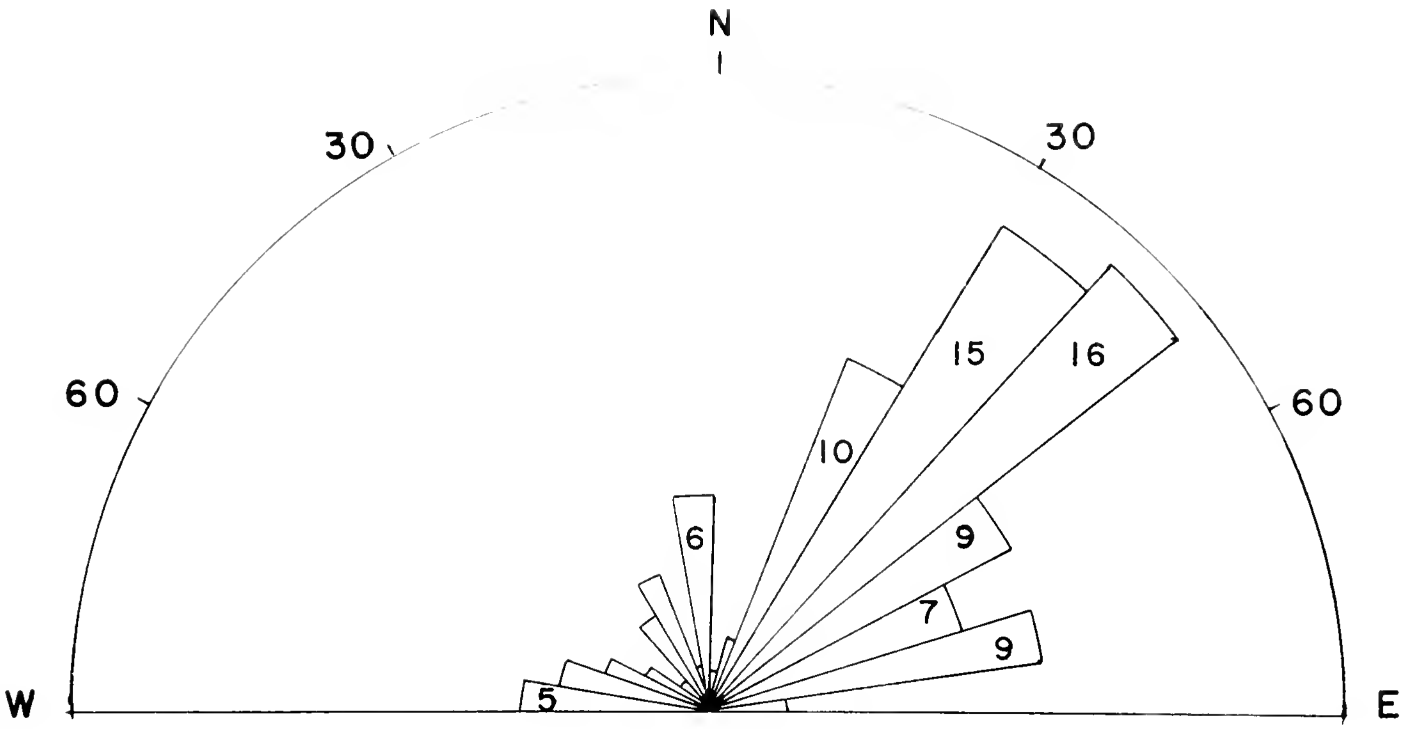


FIGURE B-3

Orientation of plant fragments within Rhode Island Formation at stop B-2 (100 measurements).

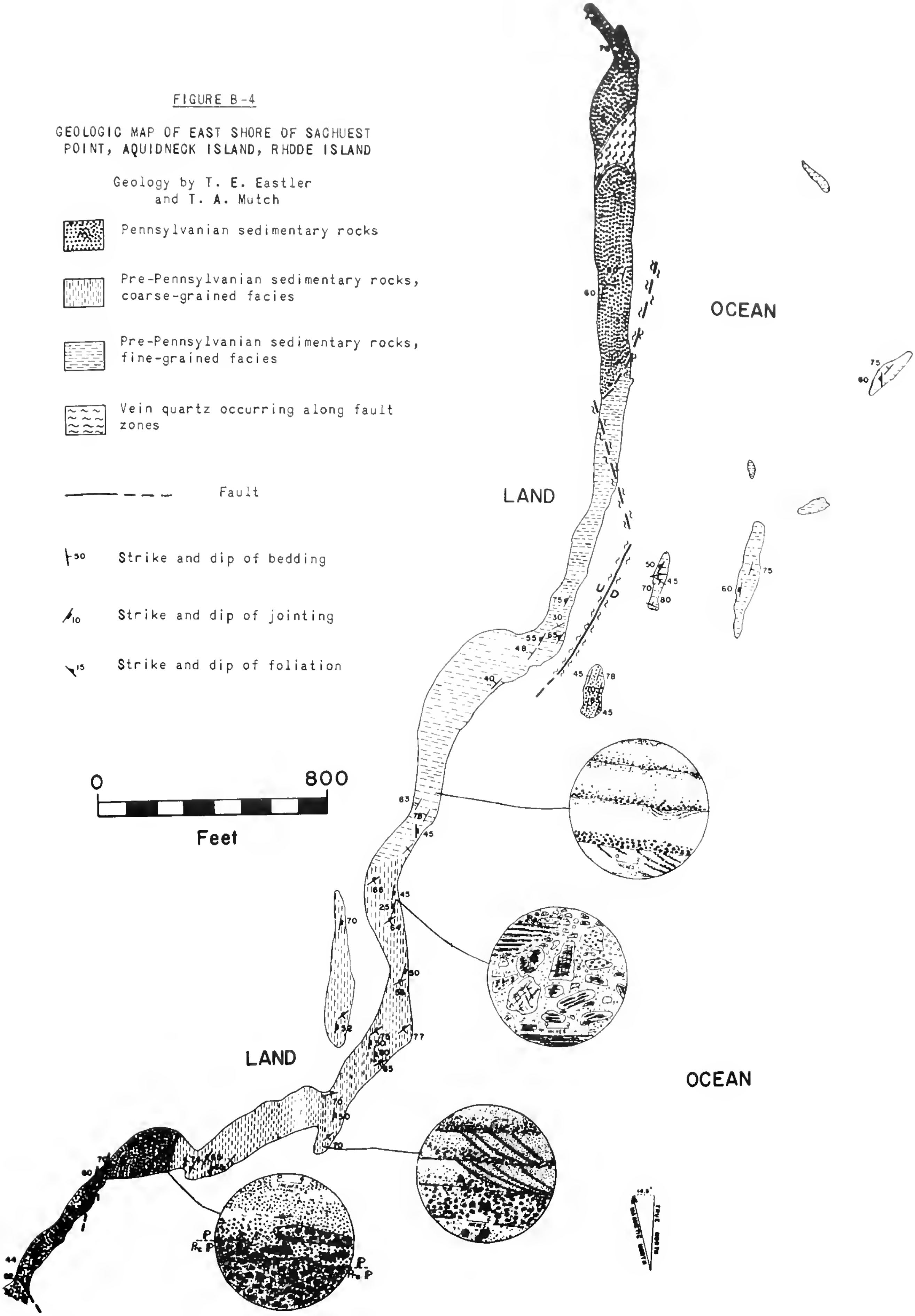


FIGURE B-4

GEOLOGIC MAP OF EAST SHORE OF SACHUEST POINT, AQUIDNECK ISLAND, RHODE ISLAND

Geology by T. E. Eastler and T. A. Mutch

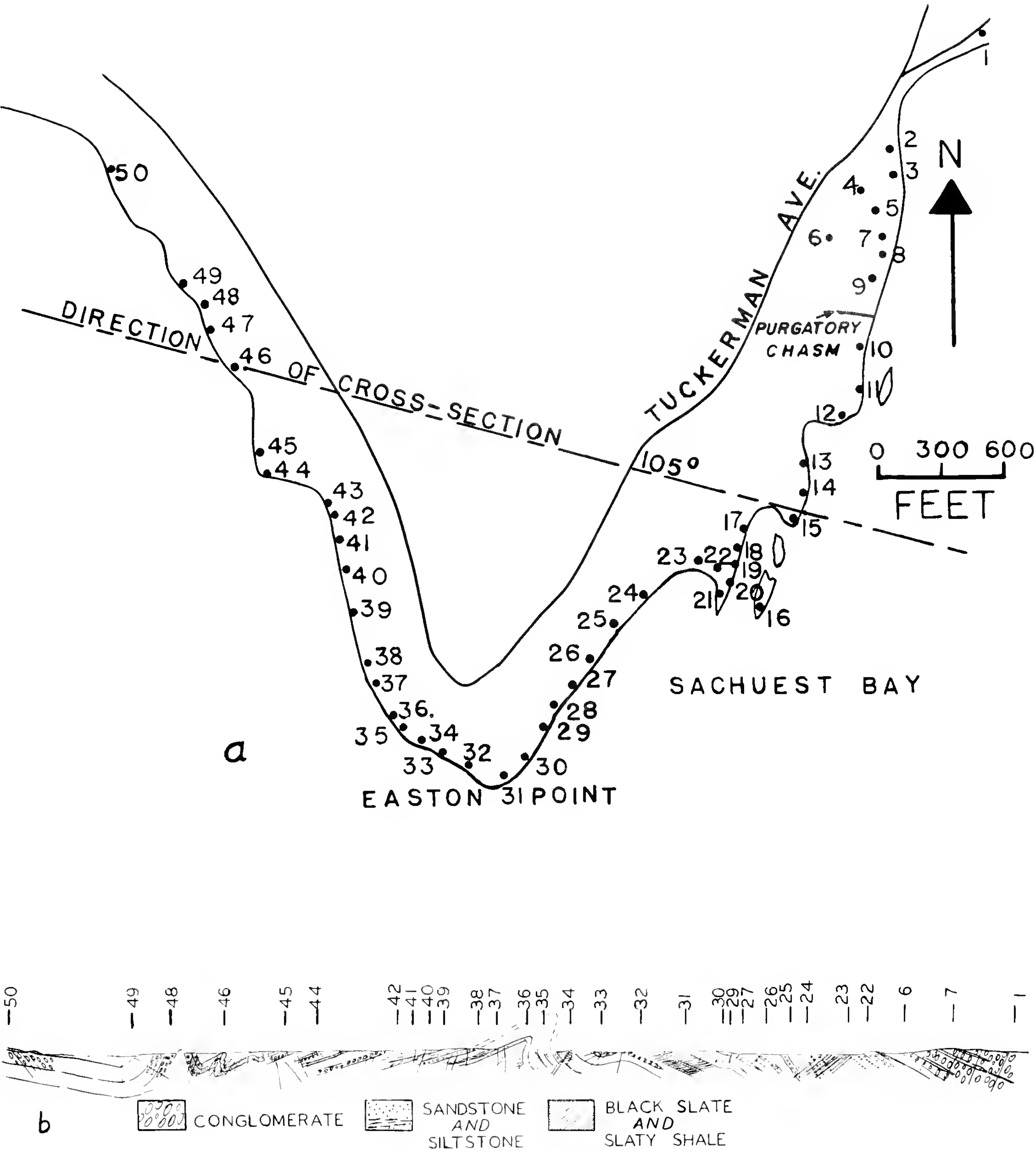


FIGURE B-5

a. Index map showing location of stations at which data were taken.

b. Preliminary composite section across Easton Peninsula along a line bearing 105°. Data projected from stations along perpendiculars to line of section.

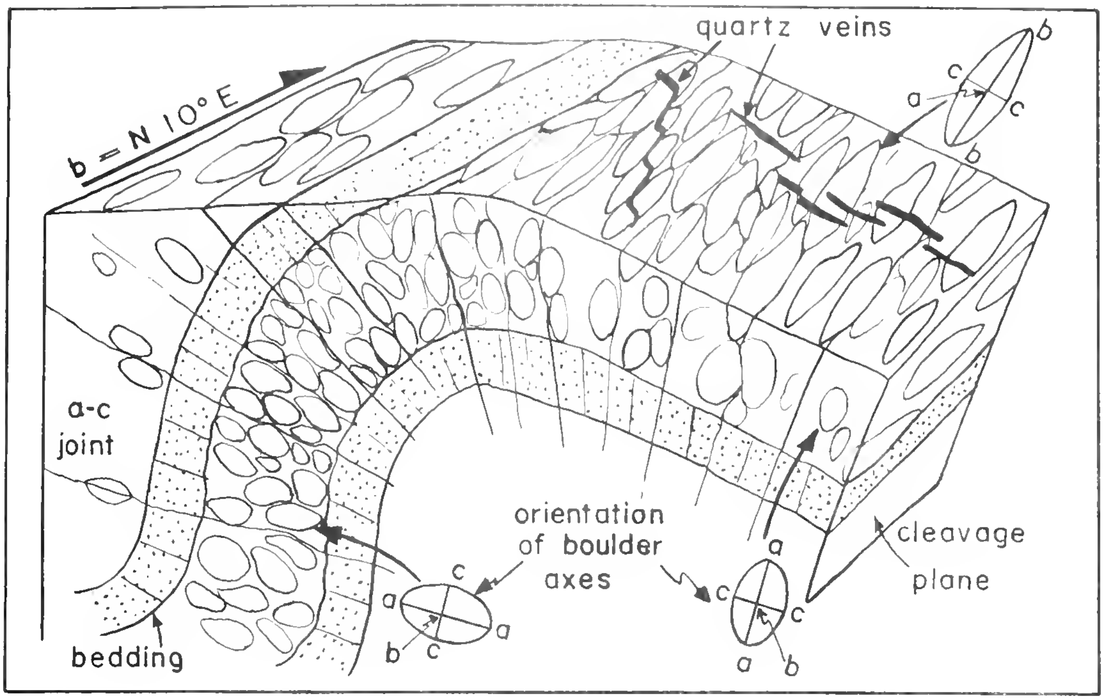


FIGURE B-6

Schematic diagram showing how flat (a-b) plane of boulders lies parallel to cleavage in a fold. Longest axis is parallel to the fold axis, b. Note two sets of quartz veins at upper right. Not drawn to scale.

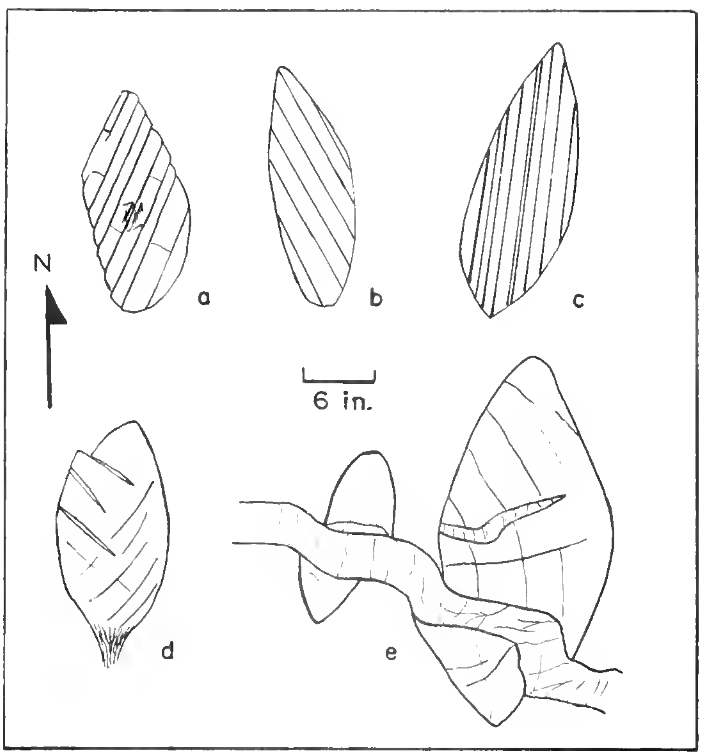


FIGURE B-7

Several elongated boulders showing fracture directions and quartz vein with offset (e).

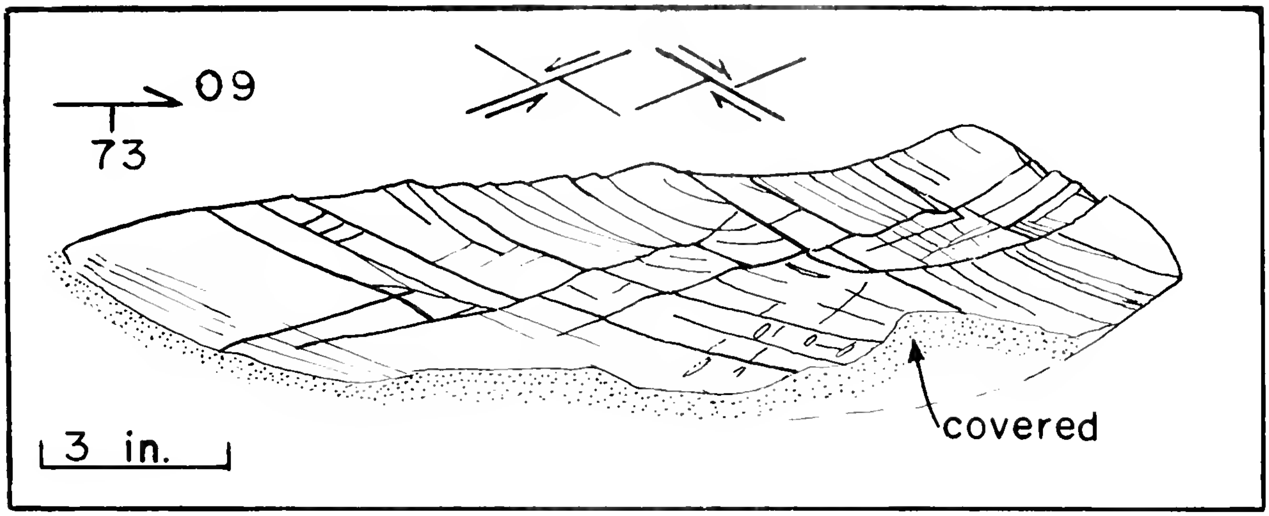


FIGURE B-8

Sheared boulder showing N-S extension and sense of movement along conjugate shears. Location 11.

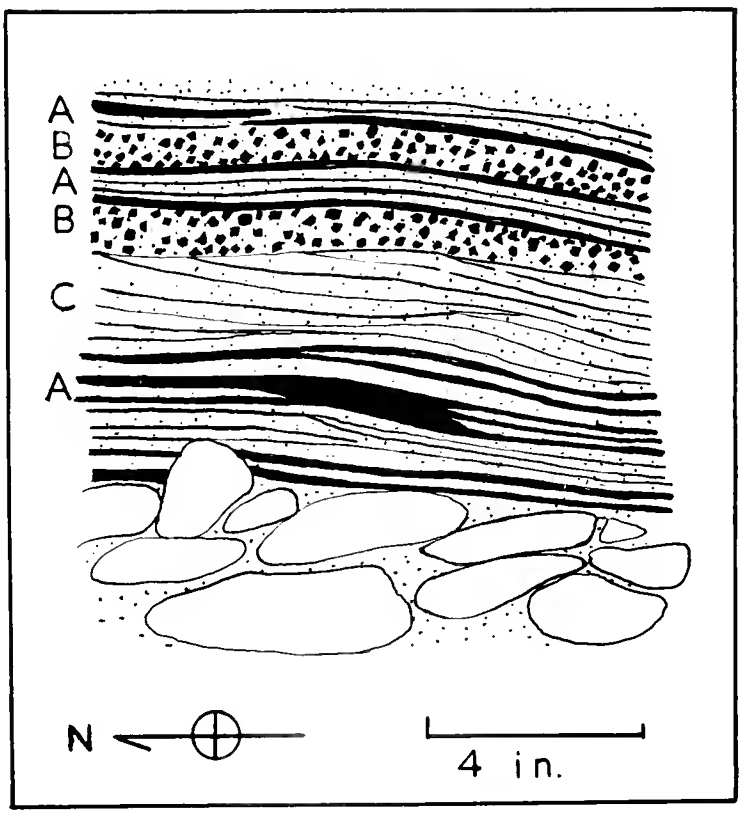


FIGURE B-9

Magnetite occurs in thick bands (A), scattered grains (B), and very thin streaks in silty beds (C). Cross-bedding in layer C indicates top is to the east. Location 4.

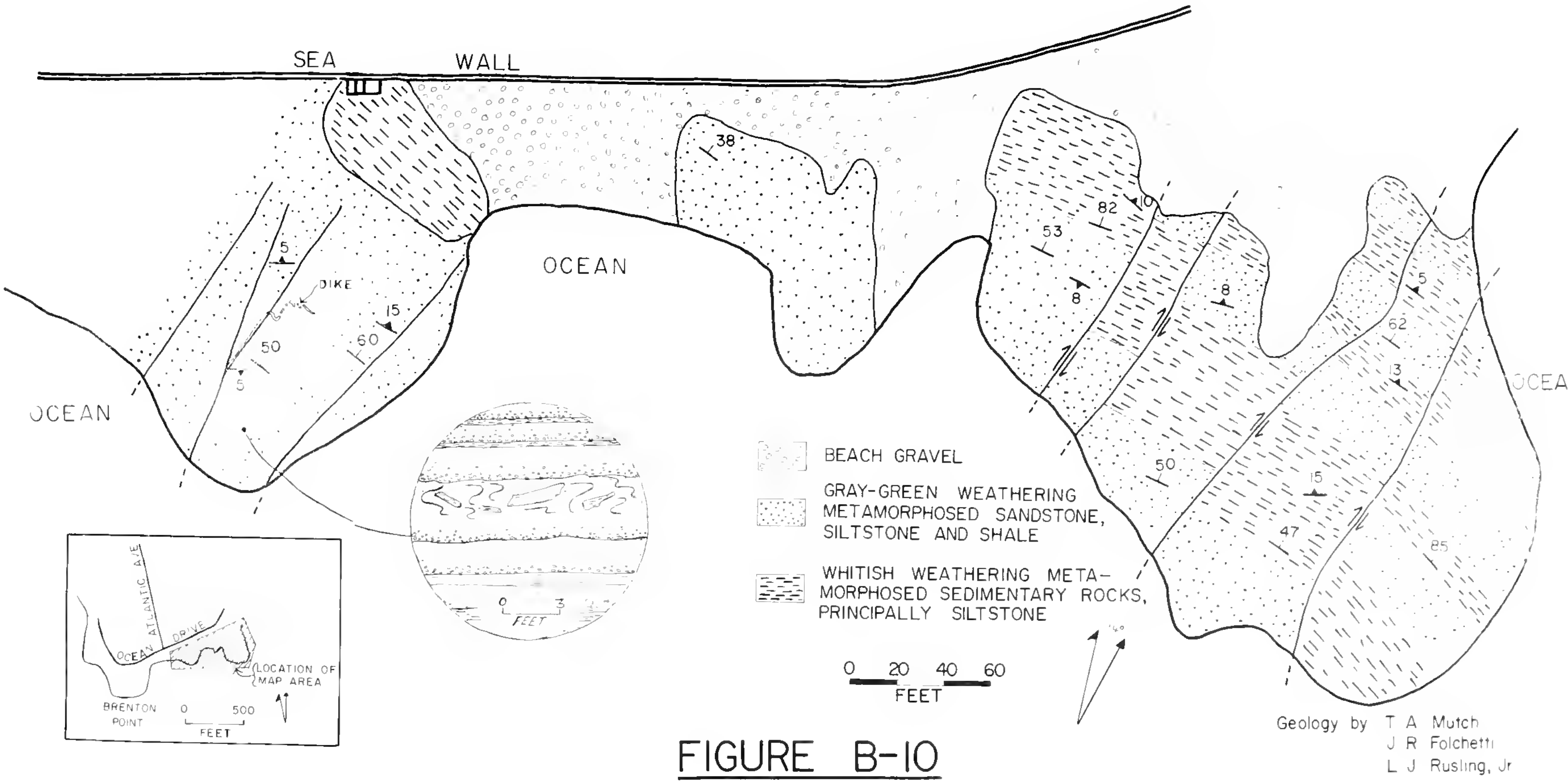


FIGURE B-10

GEOLOGY AT STOP B-5

TRIP C

GLACIAL GEOLOGY, PROVIDENCE TO POINT JUDITH

(Publication authorized by the Director, U. S. Geological Survey)

J. P. Schafer, U.S. Geological Survey

Map Coverage

Map Coverage For Trip C, Glacial Geology, J. P. Schafer:

Topographic maps (1:24,000):

Providence, East Greenwich, Crompton, Wickford, Narragansett Pier, Kingston, and Slocum; Rhode Island.

Surficial Geologic Quadrangle Maps: (all available from Map Information Office, U.S. Geological Survey, G.S.A. Building, Washington 25, D.C., at $1.00 each)

Providence, GQ-84
East Greenwich, GQ-62
Crompton, GQ-94
Wickford, GQ-136
Narragansett Pier, GQ-140
Slocum, GQ-106

U.S. Geological Survey Bulletin 1071-I, Surficial geology of the Kingston quadrangle, Rhode Island; available at $1.50 from Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

Itinerary

EN ROUTE TO STOP 1 (9 miles)

We cross, on Routes 2 and 3, an extensive kettled outwash plain in Providence and Cranston, and then a long hill of Pennsylvanian metasedimentary rocks veneered by dark-gray till (Smith, 1956a).

STOP 1. Gravel pit at Pontiac, on east side of Routes 2 and 3, East Greenwich quad. (235,500 ft. N, 505,700 ft. E; State plane coordinates, shown by 10,000-foot tick marks on margins of topographic maps.)

This section in partly collapsed ice-contact deposits (Smith, 1955) shows:

5. Late-glacial eolian silty sand, with ventifacts.
4. Stratified sand; perhaps mostly eolian sand deposited in a pond.
3. Glaciofluvial gravel and sand; thicker westward.
2. Dark-gray flowtill, rich in Pennsylvanian rock debris; stones are mostly rounded pebbles and cobbles from gravel; probably deposited as a mudflow from adjacent dead ice mantled by ablation moraine.
1. Glaciofluvial gravel and sand.

The excavation here uncovered Pennsylvanian sandstone; glacial grooves are N 20-70° W

EN ROUTE TO STOP 2 (4 miles)

We travel generally westward, first along the swampy floodplain of the Pawtuxet River, then up the marginal scarp of the Narragansett basin (outcrops

of basal Pennsylvanian conglomerate on scarp south of road) and across the upland of crystalline rocks.

STOP 2. Rottenstone pit, north of Harris, Crompton quad. (235,400 ft. N, 491,600 ft. E)

This pit is in one of several Rhode Island areas of weathered bedrock (Smith, 1956b). The weathering occurs mostly in coarse-grained granitic rocks, and penetrates locally to depths of at least a few tens of feet. As the weathered rock is overlain at many places by unweathered till, the weathering occurred before the last glaciation, and is of interglacial or preglacial age. The weathering generally consists of disintegration caused by a rather small amount of decomposition of feldspar and biotite. The resulting gruss, commonly known as rottenstone, is excavated for such uses as surfacing driveways. The rock in this pit is gray perthitic granite, composed mainly of quartz, microperthite, and biotite. The weathered rock shows a platy structure that is independent of foliation and is generally parallel to the surface. Joint-controlled spheroidal weathering is shown by the core stones, which at this pit are unusually flat ellipsoids, and by the rock surface beneath the gruss. The rounded outcrops of relatively sound rock just north of the pit are essentially glaciated tors. Much more strongly decomposed rock, representing a higher part of the original weathering profile, has been found at a few places in the State.

EN ROUTE TO STOP 3 (6 miles)

We go a short distance north past other rottenstone exposures; then south through West Warwick, mostly on till; and southwest on New London Turnpike, onto a collapsed glaciofluvial terrace at 240-280 feet, and to the head of a higher terrace.

STOP 3. Gravel pit in esker, northeast of intersection of New London Turnpike and Arnold Road, Crompton quad. (212,000 ft. N, 488,500 ft. E)

STOP 4. Gravel pit at crest of ice-contact slope, 1000 feet southeast of Stop 3, Crompton quad. (211,700 ft. N, 489,200 ft. E)

These two pits show the materials and structures at the collapsed ice-contact head of a 330-350-foot terrace, higher and older than the 240-280-foot terrace that we crossed immediately to the north (Smith, 1956b). The disappearance of the last ice sheet from much of southern New England is recorded by such bodies of stratified drift, each with an ice-contact head built against or on the edge of the stagnant marginal zone of the ice. These chronologic units have been called sequences.

The esker at Stop 3 is composed mostly of relatively well bedded and well sorted gravel and sand, strongly collapsed on both sides of the ridge. Kettle deposits are banked against the ridge, which may well have been formed in a tunnel rather than in an open channel.

The pit at Stop 4 includes much material that is cruder than that at Stop 3 -- gravel and sand of various degrees of sorting and bedding, and some till masses. Boulders are abundant, and some are of rottenstone. Several small kettles are filled with thick eolian material. The pit bottomed on bedrock, unweathered Scituate Granite Gneiss, glacially polished but not striated.

EN ROUTE TO STOP 5 (24 miles)

This part of the trip may be divided into segments as follows:

a) 5 miles; east on Division Street and then south on Route 2 to Frenchtown, mostly over till-mantled crystalline bedrock upland.
b) 7 miles; south on Route 2 and then Colonel Rodman Highway to Allenton, over ice-contact glaciofluvial deposits and "morainic kames" (knobs of unpredictable mixtures of till and sorted materials; Schafer, 1961a).
c) 1½ miles; detour onto Old Post Road, across a 40-50-foot terrace and up ice-contact head onto a 110-130-foot terrace (Schafer, 1961a); road follows crest of a steep-sided esker for part of climb up slope; relations very similar to those between the two terraces at Stops 3 and 4.
d) 6 miles; south on Tower Hill Road (US 1, formerly US 1A) to Wakefield, over a long till-bedrock hill.
e) 4 miles; south on Point Judith Road along crest of Point Judith Neck; ablation-moraine deposits mapped as the Point Judith moraine (Schafer, 1961b), believed to have been deposited at the west side of the Narragansett Bay-Buzzards Bay ice lobe; but the north part of this ridge conceals a bedrock high.

STOP 5. Lunch at seafood restaurant at Galilee, Kingston quad.

EN ROUTE TO STOP 6 (2½ miles).

We travel southeast along Sand Hill Cove beach, the easternmost of the long beaches between Watch Hill and Point Judith, and across ablation moraine to Point Judith.

STOP 6. Sea cliff at Breakwater Village (Point Judith village on topographic map), Narragansett Pier quad. (102,400 ft. N, 502,700 ft. E)

This cliff exposes till and till-like material locally overlain by or interbedded with sand and silt. The stratification is more or less deformed, presumably as a result of collapse. However, some of the strong contortion in the upper few feet appears to die out downward, and may be a result of late-glacial frost action. The drift is overlain by late-glacial eolian sandy silt that contains ventifacts.

Stones of gray Pennsylvanian sedimentary rocks are abundant, although this locality is outside the Narragansett basin. Two cobbles of cumberlandite found on the beach here represent the west edge of the indicator fan of this distinctive rock type, derived from an outcrop area 44 miles north. The thinness of the beach deposit is shown by the patches of bare till platform on the foreshore.

The short, low cliff just west of the main cliff shows a soil profile developed under poorly drained conditions. The sag between this cliff and the main cliff is the landward side of a former shallow kettle, now breached by marine erosion. A remnant of an organic deposit in this kettle is exposed on the beach and contains abundant wood, many pieces of which show beaver tooth marks (Kaye, 1962). A radiocarbon date (OWU-22) of about 10,850 years B.P. has been obtained from this deposit.

EN ROUTE TO STOP 7 (11½ miles).

We return north along Point Judith Neck to Wakefield, and then cross the head of Point Judith Pond on the new bypass. US 1 goes west and southwest across ablation moraine, around the east end of the Charlestown moraine, and then west along the foot of the moraine, with outwash plain and low till areas south of the highway.

STOP 7. Cuts on north side of Post Road (US 1), just west of Gravelly Hill Road, Kingston quad. (114,350 ft. N, 477,350 ft. E)

The Charlestown moraine has recently been described and interpreted by Kaye (1960). This moraine, which is presumably correlative with the Harbor Hill moraine of Long Island and the moraines of Cape Cod, was formed from a belt of thick ablation moraine along the ice front, derived probably from a zone of shear planes. The present complex topography and structure of the moraine were developed by lowering and lateral shifting of the ablation moraine as the dead ice beneath it melted. This topography is essentially an inverted image of the ice surface during the last stages of wastage. Among the morphological types thus produced are ice-fracture fillings, colluvial ramparts, and ice-block casts (rimmed mounds).

At Stop 7, a private road cuts through a colluvial rampart of crudely stratified, light-gray, sandy till derived mostly from granitic rocks. Such marginal ridges probably formed from material sloughed down the steep side of the ice-cored moraine. Just to the north, an old pit in the side of a small ice-block cast exposes horizontally bedded sand overlying till. Such mounds are thought to have formed by filling of a hole in the ice caused by differential melting of a fracture-bounded ice block.

EN ROUTE TO STOP 8 ($8\frac{1}{2}$ miles).

We return a mile east along the moraine front, then turn north on Ministerial Road and cross the moraine, here about $1\frac{1}{2}$ miles wide. The road crosses several ice-fracture fillings and much strongly kettled topography; Broad Hill just west of the road is a large rimmed mound. North of the moraine, we cross collapsed glaciofluvial deposits and a till ridge (Tobey Neck), and continue north-northeast through West Kingston on a broad outwash plain, the south part of which was probably built as a delta into a glacial lake in the Worden Pond basin.

STOP 8. Gravel pit about 3/4 mile north of University of Rhode Island, Kingston quad. (150,600 ft. N, 491,000 ft. E)

The outwash is somewhat collapsed toward the contoured kettle on the north side of the pit, and the till of the adjacent hill is exposed beneath a thin wedge of gravel on the east side. In much of the pit the top of the outwash is a thin, poorly sorted mudflow layer. The terrace is covered by eolian sandy silt that contains ventifacts.

This pit for several years has consistently provided the best exposures of late-glacial frost features in Rhode Island. The south and west parts of the pit show abundant involutions of the eolian material and the top of the gravel. The involutions are nearly symmetrical in vertical section and equidimensional in horizontal section, and may easily be distinguished from load casts or windthrow structures. About ten ice-wedge structures have been exposed here; they vary from 1 to 2 feet wide at the top, and end at depths of 6 to 10 feet. They occur only as separate structures, not as nets, and the late-glacial permafrost may have been only thin and patchy and of short duration.

The kettle is partly filled with a poorly sorted solifluction deposit, and involutions on its east slope are overturned. The east side of the pit exposes solifluction tongues, composed of eolian material and boulders, that extended from the hillside onto the edge of the terrace

EN ROUTE TO STOP 9 (½ mile).

We travel north on the outwash plain to its head.

STOP 9. End moraine east of Hundred Acre Pond, Slocum quad. (152,300 ft. N, 491,500 ft. E)

This narrow belt of bouldery knobs (Power, 1957) stands about 20 feet above the head of the outwash plain that includes Stop 8. A small pit beside the road shows collapsed sand and gravel, with many boulders and a few lenses of till-like material. This small moraine is likely correlative with similar features in the north-central and northwest parts of the Kingston quadrangle (Kaye, 1960, p. 381-382), and perhaps with a discontinuous moraine line extending west to Niantic, Conn. (unpublished information, Richard Goldsmith and J. P. Schafer). In southern New England, such small discontinuous moraines are known only within 20 miles of the south shore, and represent minor still-stands during the early part of retreat of the ice from the Charlestown moraine.

RETURN TO PROVIDENCE (33 miles).

We go south to Kingston, east on Route 138 to US 1 (formerly US 1A), and back to Providence on US 1 and Route 2.

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-----, 1956b, Surficial geology of the Crompton quadrangle, Rhode Island: U. S. Geol. Survey Geol. Quad. Map GQ-94.

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-----, 1961c, Correlation of end moraines in southern Rhode Island: U. S. Geol. Survey. Prof. Paper 424-D, p. 68-70.

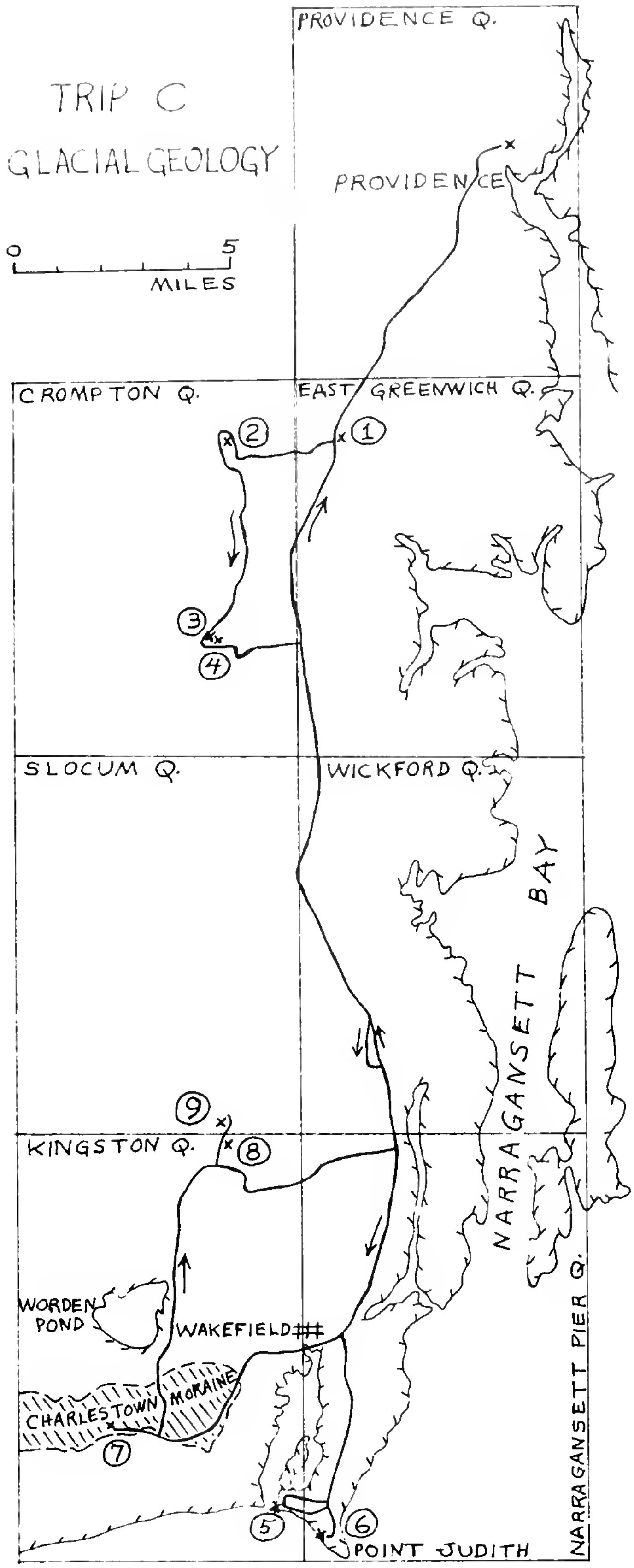

FIGURE C-1

Sketch Map of eastern and southern Rhode Island, showing localities for glacial trip.

PLUTONIC ROCKS OF NORTHERN RHODE ISLAND

Alonzo W. Quinn, Brown University

Itinerary

STOP 1 - Assemble at 9:00, Sunday, October 6 Iron Mine Hill, "Iron Trap Rock Quarry", Cumberlandite. Franklin quadrangle.

This is a little more than 12½ miles northwest of Providence, about 3 miles east of Woonsocket, and 2½ miles west of Diamond Hill.

From Providence either

(1) drive north on Rtes 1 and 114, 12½ miles to Rte. 11; left (W) on Rte. 11 (Wrentham Rd.) 1½ miles to West Wrentham Rd.; left (S) on West Wrentham Rd., ½ mi. to Elder Ballou Meeting House Rd.; right (W) 2/10 mi. to quarry.

or (2) drive north and northwest on Rtes. 1 and 122, 11 3/4 miles through Cumberland Hill to West Wrentham Rd.; right (N) on West Wrentham Rd., 1 3/4 miles to Elder Ballou Meeting House Rd.; left (W) 2/10 mile to quarry.

Cumberlandite, the titaniferous magnetite rock at Iron Mine Hill, Rhode Island, has been known for 260 years or more. The peculiar character of the rock and the possibility of economic use have attracted the attention of many people, with the result that many articles and reports have been written about it. The most useful of these reports are one by Johnson in 1908 and one by Singewald in 1913 (see References).

Johnson (1908, pp. 2, 3) reported that a few thousands of tons of the cumberlandite had been used as iron ore by mixing with non-titaniferous ores from various other areas. The earliest use reported was in 1703 when it was mixed with ore from Cranston, R. I. Cannon made this ore are said to have been used in the siege of Louisburg in 1745 and probably in the Revolutionary War. The greatest use of this rock has been as crushed stone for roads and driveways.

The mineral composition, the texture, the general field relations, and the presence of inclusions of gabbro within the cumberlandite indicate that it is an intrusive igneous rock.

The country rock includes, in order of probable age from oldest to youngest, quartz-mica schist of the Blackstone series (Precambrian ?), gabbro, Esmond granite (Devonian ? or older), and Quincy granite (Mississippian ?). The Blackstone is definitely intruded by the Esmond granite and almost certainly by the gabbro and the cumberlandite. Relations here do not reveal the age relations of the Esmond granite to the Gabbro, but Warren and Powers (1914, p. 450), reported that ~~the~~ at Sheldonville, Mass., a similar gabbro is intruded by biotite granite that is probably related to the Esmond granite. In the Pawtucket quadrangle to the south the Quincy granite intrudes the Esmond (Quinn GQ1). It is not known whether the cumberlandite is older or younger than either the Esmond granite or the Quincy granite.

Warren (1908, p. 25) indicated that the mineral composition of the unaltered

rock in percent by volume is: olivine 49.4, magnetite 15.9, ilmenite 15.2, labradorite 13.7, spinel 3.6, sulfides 1.1, and orthoclase 0.8. The magnetite and ilmenite are intimately intergrown. At present very little unaltered rock can be found, although an area three or four hundred feet square is said to have been present on the west side of the hill. In most of the rock the olivine and the labradorite have been replaced by serpentine, chlorite, or actinolite.

Several chemical analyses are listed in Singewald (1913, p. 44). The most accurate and complete, by Warren (1908, p. 24) is: SiO_2 22.35, Al_2O_3 5.26, Fe_2O_3 14.05, V_2O_3 .18, Cr_2O_3 tr., FeO 28.84, MgO 16.10, CaO 1.17, Na_2O .44, K_2O .10, H_2O .42, CO_2 .02, TiO_2 10.11, P_2O_5 .02, S .38, MnO .43, Zn .71, Cu .08, Co&Ni .08, Pb. tr.

The average of 10 analyses gives Fe 33.49 and TiO_2 9.75.

The specific gravity of the unaltered rock is 3.9 to 4.0 and of the altered rock 3.6 to 3.8.

The cumberlandite makes an almost ideal boulder train - a peculiar and easily recognized rock, with one small source area. Most of the boulders have been found on the islands of Narragansett Bay as far as Newport; very few have been found on the west side of the bay.

<u>Miles</u>

00.0 Drive east from quarry.
00.2 Right on West Wrentham Rd.
00.9 Tower Hill Rd. on left.
1.1 <u>STOP 2</u> - Pawtucket quadrangle, GQ1.
Quincy granite (microperthite, quartz, riebeckite, aegirite) on both sides of road, coarse and fine-grained facies, flow structures dipping north; joints and shear surfaces coated with riebeckite, astrophyllite, fluorite, etc. Cumberlandite boulders common in drift.
2.1 Left on Rte. 122.
2.3 Cumberland Hill.
Continue south on Rte. 122, in Sneech Pond Schist, which is not much exposed here.
5.0 Westboro Quartzite on right.
Quartzite appears to be a strong massive rock, and yet the Blackstone River has cut its valley in it as though it were the least resistant rock.
5.4 Right on Rte. 116 (continue on Rte. 116 to Rte. 44).
5.5 Crossing Blackstone River.
7.3 Under Rte. 146; Hunting Hill Greenstone of Blackstone Series exposed.
8.0 Esmond granite exposed along road most of way to next stop.
8.1 Pass entrance to North Central Airport.
10.5 Cross Rte. 7.
11.3 Washington Grove
<u>STOP 3</u> - Georgiaville quadrangle, GQ16.
Scituate Granite Gneiss.
Please do any rock-breaking in peripheral woods area where it will not spoil this public grove.
11.5 Stillwater Reservoir.
11.6 Left on Rtes. 116, 104, and 5
11.8 Right on Rtes. 116 and 5.
12.4 Woonasquatucket Reservoir.
East margin of North Scituate basin of Pennsylvanian comes through here, but drift cover here is complete

Miles

13.7 Bear right on Rte. 116 (Rte. 5 goes left).
14.6 Right on Rte. 44.
Greenville
15.7 West margin North Scituate basin; meta-diorite on left.
16.1 Waterman Reservoir
17.3 Harmony
18.0 Turn into abandoned piece of road.

STOP 4 - Georgiaville quadrangle, GQ16
Walk back along main road (Rte. 44).
Beware of traffic.
Woonasquatucket Formation, the youngest of Richmond's "older Gneisses".

STOP 5 - Chepachet quadrangle.
19.1 Absalona Porphyroblastic Gneiss, middle formation of "older gneisses".
19.2-19.9 Light gneiss within Absalona.
21.3 Acote Hill on right. (Dorr rebellion fizzled as a military venture here in 1842, one cow and one bystander killed).
Continue on Rte. 44.
22.0 Chepachet. Continue on Rte. 44.
23.5 Right on Reservoir Road.

25.6 STOP 6 - Chepachet quadrangle.
Leduc's Boat House. Park on left side of road, or ahead and right in parking lot.
Garvy Ledge quarry. Gneiss containing many relicts.

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Singewald, J. T., 1913, The titaniferous iron ~~from~~ ores in the United States: U. S. Bur. Mines, Bull. 64, 145 p. (Iron Mine Hill, p. 40-46).

Warren, C. H., and Powers, Sidney, 1914, Geology of the Diamond Hill-Cumberland district in Rhode Island-Massachusetts: Geol. Soc. America Bull., v. 25, p. 435-476.

TRIP E

GEOLOGY OF CLIFF WALK, NEWPORT

Thomas A. Mutch, Brown University

Introduction

This field trip will consist of a walk along a portion of the Cliff Walk, Newport. A variety of Pennsylvanian and pre-Pennsylvanian sedimentary and igneous rocks are well displayed in the cliff. The walk is doubly interesting because of the views presented of some of the Newport mansions which border the ocean. Most of these "summer cottages" were built during 1890-1910 when Newport was an important summer resort. A few of the mansions are still occupied by private families but many now serve as museums and schools or simply stand unoccupied. Figure E-1 shows the location of some of the more important mansions.

During the period when Newport was a prominent resort a number of geologists visited the area and published accounts of the local geology. Pirsson (1893) believed that the rocks exposed directly north of the granite on Cliff Walk were contact metamorphosed Pennsylvanian sedimentary rocks and that the metamorphic contact between these rocks and demonstrable Pennsylvanian rocks along the northern part of the Cliff Walk was gradational. Crosby (1897) pointed out that the contact was not gradational and that the two sedimentary sequences were fundamentally different Referring to the older sequence he said "the flinty slate resembles no other formation in New England so closely as the Middle Cambrian slates of the Boston Basin, many of the ledges being indistinguishable from the more characteristic outcrops of the Blue Hills." (p. 232).

Itinerary

From Brown University proceed several blocks east to Hope Street and go south on Hope until it ends at a stop light. Turn left (east) on four lane road, across Washington Bridge. Follow Rt. 195 (continuation of four lane road) for about ten miles. Turn south on Rte. 136 and follow it across Mt. Hope Bridge. Just after the bridge bear right on Rte. 114. Follow for 1.4 miles and go straight through light. Follow for .7 miles and bear right on Rte. 138. Follow 138 for approximately six miles. Just past large tree nursery take left on Rte. 138A (Aquidneck Ave.). Follow this road to ocean and turn right (west) on Memorial Blvd. Follow 1.4 miles to Bellevue Ave. and turn left (south) on Bellevue. Follow for 1.2 miles and turn left (east) on Marine Ave. Follow to ocean.

STOP E-1 - Vein quartz in Pennsylvanian sedimentary rocks. Bedding and foliation are approximately parallel, N10E, 40W. See Figure E-2 for location of this and following stops.

STOP E-2 - Pennsylvanian sandstone, siltstone and shale. Prominent foliation, N10E, 45W obscures bedding which is variable. Laminated siltstones at top of outcrop strike N55E and dip steeply to the SE. Good view of "The Breakers" looking north along cliff walk.

STOP E-3 - Deformed Pennsylvanian sandstones and shales exposed just north of fault separating these rocks from pre-Pennsylvanian rocks. Bedding and foliation are approximately parallel, N40E, 35NW. Isolated sandstone slab occurs

along small fault. Quartz granule sandstones are similar to those appearing near base of section at Sachuest Point, suggesting that there may not be large displacement along fault directly to south.

STOP E-4 - Pre-Pennsylvanian sandstone and siltstone oriented N80E, 75N. Rocks are lithologically similar to pre-Pennsylvanian rocks exposed on Sachuest Point and portions of Newport Neck. Glacial polish and striations are well developed along the outcrop. Cumberlandite boulders might be seen in drift. The source for these is about 35 miles north.

STOP E-5 - Intrusive contact between pre-Pennsylvanian rocks and porphyritic hornblende granite. Sedimentary rocks are intruded by dikes, sills, and blebs of granitic material. Plastic flowage of country rocks is apparent and numerous small faults have displaced sedimentary rocks and small intrusive bodies included within them. Similar porphyritic granite is overlain by Pennsylvanian rocks with angular unconformity on Conanicut Island, five miles to the west, suggesting pre-Pennsylvanian age for granite along Cliff Walk.

Return to cars along same route.

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Crosby, W. O., 1897, Contribution to the geology of Newport Neck and Conanicut Island: Am. Jour. Sci., 4th ser., vol. 3, p. 230-236.

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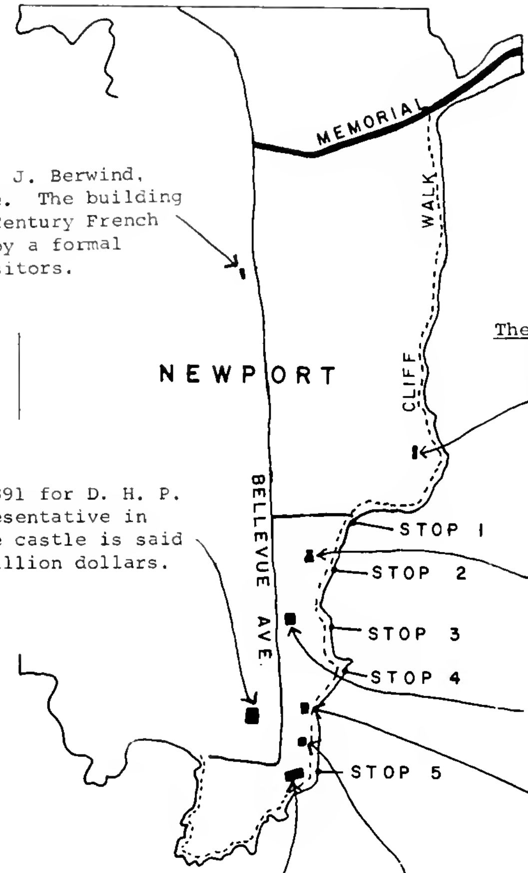
FIGURE E-1



The Elms - Built in 1901 for E. J. Berwind, a Philadelphia coal magnate. The building was modeled after an 18th Century French Chateau and is surrounded by a formal French garden. Open to visitors.

The Breakers - Built in 1895 for Cornelius Vanderbilt. Constructed in the style of the Italian Renaissance, the house has four floors with approximately seventy rooms. The first and second floors are open to visitors.

Belcourt Castle - Built in 1891 for D. H. P. Belmont, Rothschild representative in America. The cost of the castle is said to have exceeded three million dollars. Open to visitors.

Rosecliff - Built in 1899 for the daughter of James G. Fair who made a fortune in the California Gold Rush.

Marble Palace - Built in 1892.

Clarendon Court

Miramar - Built in 1914. Purchased by Episcopal Church several years ago.

Rough Point - Built for Frederick Vanderbilt in 1890. Now owned by Mrs. Doris Duke Cromwell.

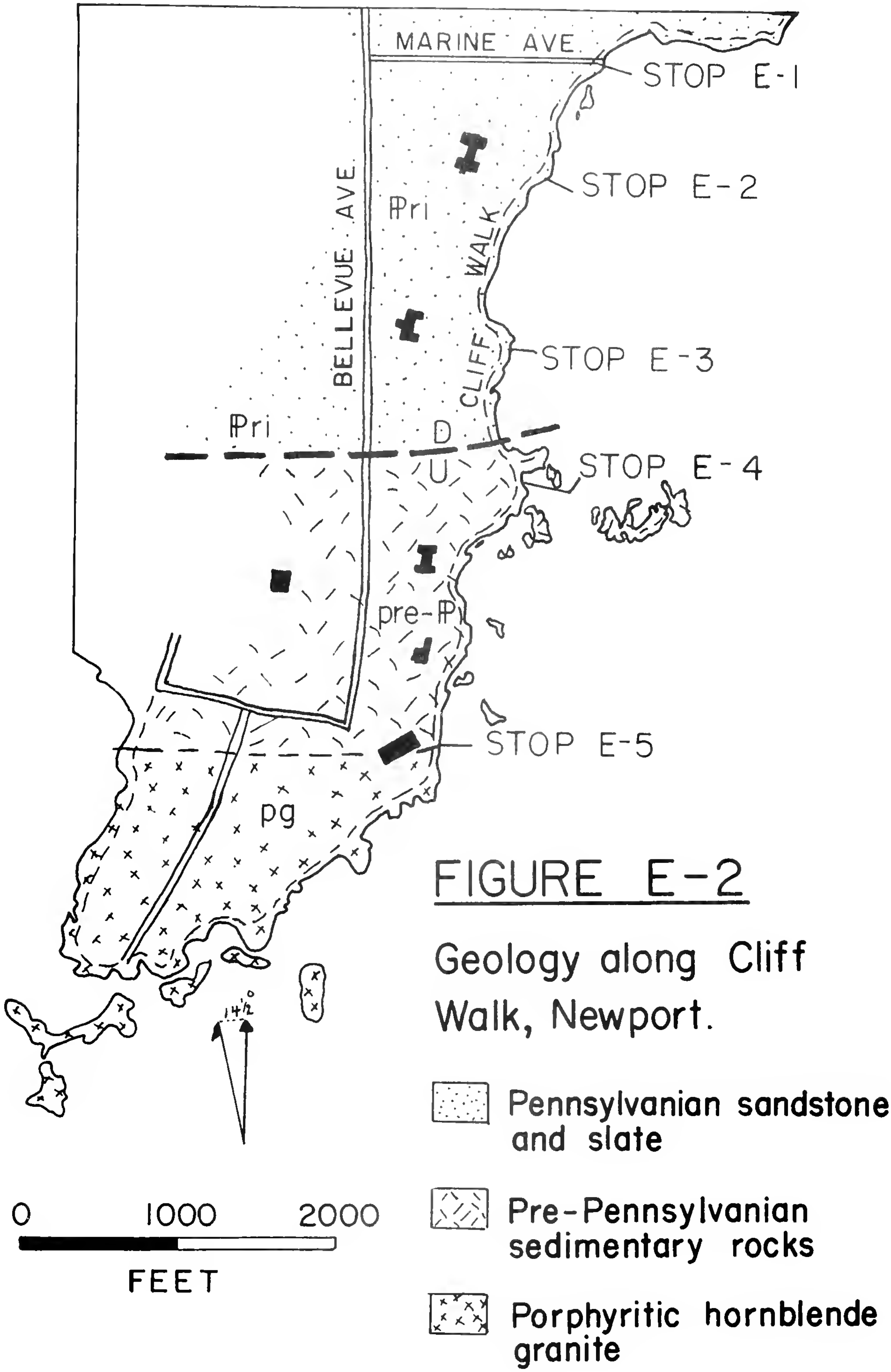


FIGURE E-2

Geology along Cliff Walk, Newport.

TRIP F

Structural Geology, Beavertail, Conanicut Island

William M. Chapple - Brown University

In the absence of the leader it is not possible to prepare an adequate guidebook and road log of this trip in time for the guidebook deadline.

Meeting Time: 9:00 A.M., October 6, 1963
Meeting Place: Rte. 138 at east end of Jamestown
Bridge (60¢ per car).

FIELD TRIP G

WESTERLY GRANITE AND RELATED ROCKS OF THE WESTERLY-BRADFORD AREA

(Publication authorized by the Director, U.S Geological Survey)

Leader: Tomas Feininger, Brown University and U.S. Geological Survey

Introduction

Westerly Granite has been quarried in the Westerly area since 1846, and at one time was the principal industry of Westerly and nearby Niantic (now Bradford), Rhode Island. The Westerly Granite is a superior statuary granite and although the area's quarry industry is now a faded relic of its former greatness, just enough demand remains to keep a quarry or two operating.

Westerly Granite is fine grained, equigranular, and light gray. It is generally almost massive, although faint primary foliation is commonly visible with a hand lens. Locally this foliation is strong near contacts with other rocks. Surface and near-surface rock is pink, and locally known as "swamp granite". The uniformity of the Westerly Granite from exposure to exposure and from body to body is exceptional for a felsic intrusive rock. This property was paramount in leading to the selection of the Westerly Granite as the reference standard G-1 (Fairbairn and others, 1951; Stevens and others, 1960). Only in very small bodies (generally less than ten feet across) is the Westerly inhomogeneous. In these it tends to be somewhat streaky, and commonly is porphyritic with phenocrysts of microcline and acicular biotite.

Westerly Granite is actually a quartz monzonite or granodiorite, bearing subequal amounts of potassium feldspar (microcline) and plagioclase (oligoclase). A mode is given below.

Geologic evidence suggests the Westerly is late or post-Pennsylvanian. Lead-alpha ages on separated zircon and monazite range from 220 to 243 m.y. (Quinn and others, 1957). More recent radiometric dating has given K-Ar ages of 240 ± 12 m.y. and Rb-Sr ages of 260 ± 13 m.y. (Hurley and others, 1960).

A granitic rock associated with and only very slightly older than the Westerly is the Narragansett Pier Granite. This pink, medium-grained granite is massive to moderately foliated, and generally equigranular. It resembles the typical "Granite" shown in Geology 1 classes around the world. The Narragansett Pier Granite is chemically and mineralogically almost identical with the Westerly (see mode given below), and is also a quartz monzonite or granodiorite. The Westerly and Narragansett Pier are probably two phases of a single magma-forming event. Lead-alpha ages on zircon separated from Narragansett Pier Granite range from 208 to 274 m.y. (Quinn and others, 1957).

Westerly Granite is principally found as a dike rock. With few exceptions the dikes strike east and dip gently to moderately southward. About 30 dikes are exposed in the Westerly area, and probably as many are exposed farther west in Connecticut.

The persistent structural setting of the Westerly Granite suggests that a regional stress pattern prevailed during intrusion. An east-trending, north-dipping low-angle thrust fault is known to traverse southeastern Connecticut (Lundgren, 1963; Snyder, 1961). Stresses that produced this fault could have produced east-west southward-dipping tensional fractures in the Westerly-Bradford area. This correlation of geologic structures of southeastern

Connecticut-southwestern Rhode Island is tentative.

Modes:

	1	2
Quartz	27.5%	27.0%
Microcline	35.4	36.0
Plagioclase	31.4	33.0
Muscovite	1.3	1.0
Biotite	3.2	2.5
Opaque	0.8	0.5
Other	0.4	trace

1. Westerly Granite, Chayes *in* Fairbairn and others, 1951, p. 61, based on average of 16 thin sections, 1500 counts each.

2. Narragansett Pier Granite, Feininger, mode made in 1960, based on average of six thin sections, 2000 counts each.

References: Selected papers on the Westerly Granite.

Fairbairn, H. W., and others, 1951, A cooperative investigation of precision and accuracy in chemical, spectrochemical and modal analysis of silicate rocks: U.S. Geol. Survey Bull. 980, 71 p.

Hall, B. A., and Eckelmann, F. D., 1961, Significance of variations in abundance of zircon and statistical parameters of zircon populations in a granodiorite dike, Bradford, Rhode Island: Am. Jour. Sci., v. 259, no. 8, p. 622-634.

Hurley, P. M., Fairbairn, H. W., Pinson, W. H., and Faure, G. 1960, Potassium-argon and rubidium-strontium minimum ages for the Pennsylvanian section in the Narragansett Basin: Geochim. et Cosmochim. Acta, v. 18, p. 247-258.

Macomber, S. W., 1958, The story of Westerly Granite: Westerly Historical Soc., 38 p.

Quinn, A. W., 1943, Settling of heavy minerals in a granodiorite dike at Bradford, Rhode Island: Am. Mineralogist, v. 28, p. 272-282.

Quinn, A. W., and others, 1957, Lead alpha ages of Rhode Island granitic rocks compared to their geologic ages: Am. Jour. Sci., v. 255, p. 547-560.

Stevens, R. E., and others, 1960 Second report on a cooperative investigation of the composition of two silicate rocks: U.S. Geol. Survey Bull. 1113, 126 p.

Other references:

Lundgren, Lawrence, Jr., 1963, The bedrock geology of the Deep River quadrangle: Connecticut Geol. and Nat. Hist. Survey, Quad. Rept. 13, 40 p.

Snyder, G. L., 1961, Bedrock geology of the Norwich quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-144

Itinerary:

The trip will be by private cars and will assemble at 9:30 AM Sunday on the R. I. Rte. 3 overpass of R. I. Rte. 95. This is about midway between Hopkinton and Ashaway, R. I. The starting point is about 40 miles from Providence, a little more than an hour's drive. The entire trip will be within the Ashaway and Carolina 7½ minute topographic quadrangles. All the stops, especially the first, third, and last, are dangerous. Please use caution when scrambling over dumps or climbing in quarries. Permission to visit the first quarry was obtained only upon the promise that all participants would sign a paper releasing the Westerly Granite Co. of Bradford, R.I. from responsibility for injuries sustained on their property.

I would like to thank Mr. Angelo M. Gencarelli, owner of the quarries at Stops 2, 3, and 4, and Mr. L. Bottinelli, and Mr. E. Monti, owners of the Crumb Quarry. Without their cooperation this trip would not have been possible.

Approx. Mileage	
00.0	R. I. Rte. 3 overpass of R. I. Rte. 95. Proceed south on Rte. 3.
01.8	Turn LEFT on Rte. 216 (Ashaway village).
04.2	Stop sign, turn RIGHT.
04.5	Cross Pawcatuck River
04.6	Bear LEFT (Bradford Village on right).
04.9	Cross main line NYNH&HRR.
05.1	Turn LEFT (follow Rte. 216).
05.8	Turn RIGHT (at sign "BEDROCK"), follow paved road.
06.4	Wide gravelled area, park for

STOP 1:

The Crumb Quarry. Typical development of the Westerly Granite is well shown in this large east-west, south-dipping dike. The bottom contact is excellently exposed, and shows the accumulation of heavy minerals in the Westerly. This is the site of the studies by Quinn (1943) and Hall and Eckelmann (1961). Other features to be discussed include jointing, primary flow structures, inclusions, and the pegmatitic nature of the contact. The host rock is the Hope Valley Alaskite Gneiss.

Turn around and go in the reverse direction on the same road.

06.9	Turn LEFT (Rte. 216).
07.7	Stop sign, turn LEFT (toward Westerly).
09.3	Bear RIGHT (follow the main road).
12.3	Extremely sharp (150^{o}) RIGHT turn onto Old Hopkinton Road.
12.4	Cross main line NYNH&HRR.
12.6	Turn LEFT onto gravel road (opposite dilapidated house in trees on right), park.

STOP 2:

Abandoned quarry. Here a different dike of Westerly Granite has intruded Narragansett Pier Granite. Exposures on the far wall are unusually clean and clearly show apophyses of the Westerly in the Narragansett Pier, partially

stoped blocks of Narragansett Pier in the Westerly, and two generations of pegmatite. The upper contact of the dike is exposed, and here dips about 40°. Note that it is locally irregular, showing that dike dip readings obtained from a single small exposure can be misleading. Note the quarried blocks lying about. Many interesting relationships can be seen in these.

Return to cars, continue to paved road.

Turn LEFT, continuing as before on Old Hopkinton Road.

13.1 Turn LEFT onto wide gravel road.

13.5 Park cars at wide gravelled area (probably to be shared with several "Euclid" trucks). Continue on foot about 500 ft. to a large operating quarry on the right.

STOP 3:

The Gencarelli Quarry. This quarry was reactivated on a large scale about three years ago, and is producing huge groin blocks for breakwaters. The Westerly dike, the same one as at the previous stop, is here 67 feet thick. Exposures are very good; however the topography of the quarry changes so rapidly with quarrying that any description made now (July, 1963) would be meaningless by October. Some features will be noted in any event, especially: 1) the top contact, here dipping 15° to 20°, and quite regular; 2) strongly developed, locally closely spaced, north-south vertical joint systems, and associated rock alteration; and 3) structures in the host Narragansett Pier Granite.

Walk back toward the cars. Approximately where the cars are parked, turn RIGHT and climb the rubble embankment on the east, walk about 300 feet farther east to

STOP 4:

Water-filled abandoned quarry. The quality of the Westerly here is poor, and the quarry probably never was successful. The quarry exposes an unusual feature, the upward termination of a dike. This is the same dike as at the two previous stops, here again in Narragansett Pier Granite which contains at least one large inclusion of gneiss. The contact between Westerly and Narragansett Pier is highly amoeboid, quite unlike that seen at the other stops. The contact will be examined, and its petrologic and structural significance will be discussed.

Return to cars

END OF TRIP

To return to starting point:

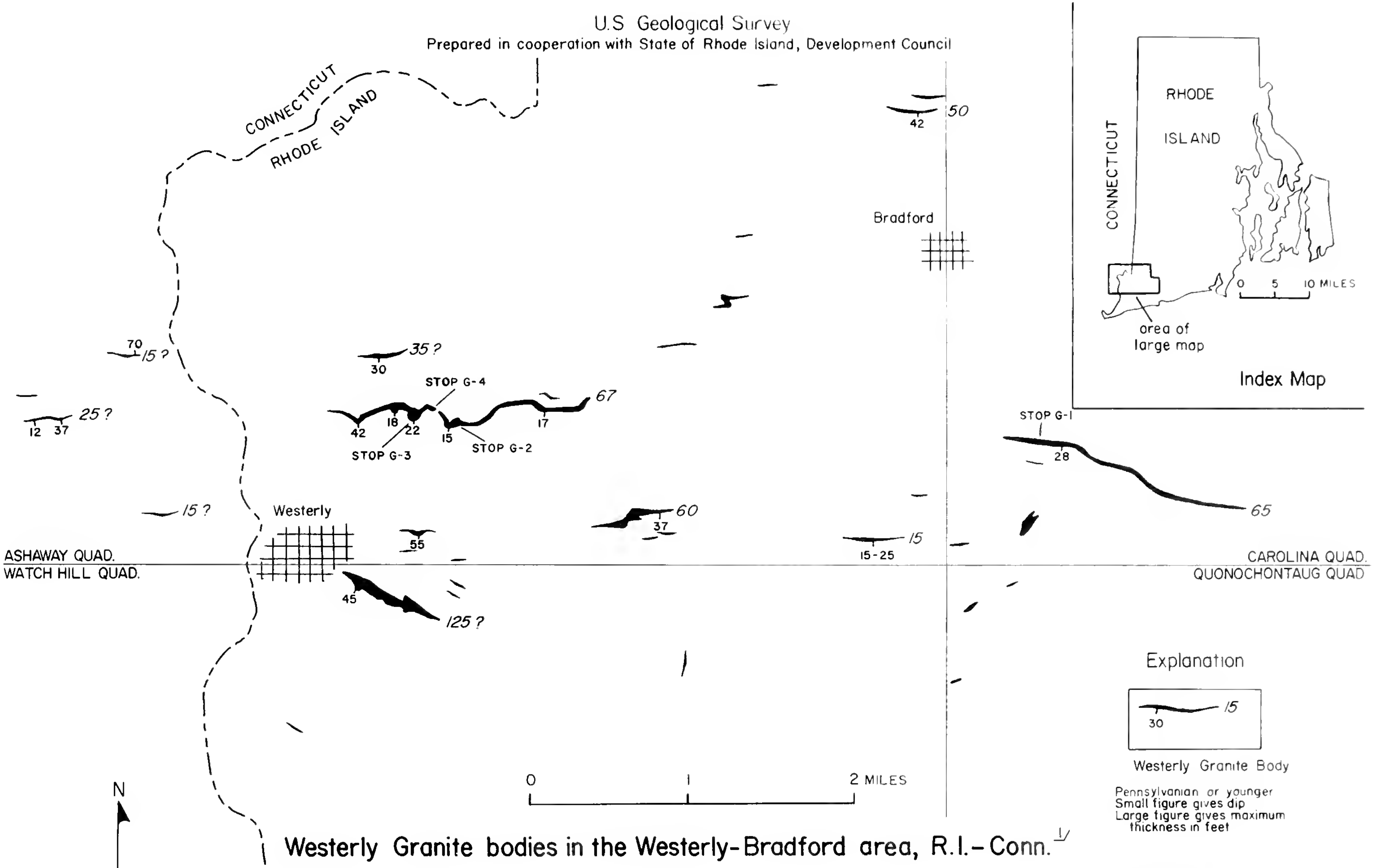
Reverse direction on wide gravel road.

13.8 LEFT fork.

14.0 Turn LEFT on paved road (Old Hopkinton Road).

14.2 Turn LEFT, stop sign immediately ahead. Cement road is R.I. Rte. 3. Left is southward toward Westerly, RIGHT is northward toward Ashaway, and

18.4 Starting point.



Westerly Granite bodies in the Westerly-Bradford area, R.I.-Conn.[1]

[1] Publication authorized by the Director, U S. Geological Survey

Granite bodies in the Ashaway quadrangle mapped by T. Feininger, others mapped by G.E. Moore, Jr.

TF NEIGC '63

FIGURE G-1

TRIP H

STRUCTURAL GEOLOGY OF WOONSOCKET AND NORTH SCITUATE BASINS

By Henry T. Hall, Brown University

General Discussion

The Woonsocket and the North Scituate basins, about 6 miles west of the Narragansett Basin, are probably of Pennsylvanian age, although conclusive fossil evidence has not been found. Stratigraphically, both basins are formed of coarse Bellingham conglomerate. The pebbles are predominantly quartzite, but some are granite and some are schist. The matrix is arkosic in places and interbeds of sandstone are common. The rocks have been strongly folded so that the pebbles are greatly stretched; the matrix is schistose. Richmond (1952 GQ16) stated that in the Georgiaville quadrangle the intensity of metamorphism increases from the south to the north, in contrast to the southerly increase in metamorphic grade in the Narragansett Basin. Microscopic study of several samples does not confirm this, but rather shows an increase in metamorphic grade to the south.

The Bellingham conglomerate rests unconformably upon pre-Pennsylvanian igneous and metamorphic rocks. The conglomerate may have been continuous with the Pennsylvanian rocks of the Narragansett Basin at one time, in which case they were subsequently eroded from the structurally high areas between the basins.

The geologic structure of the Woonsocket and North Scituate basins is simple in its broad outline, but very complex in detail. Figure 1 is a geologic sketch map of the basins with some stereographic nets showing the macroscopic geometry of the folds. Figure H2 shows two alternative interpretations of the geologic section of the North Scituate basin. Richmond (1952), on the basis of the general easterly dip of bedding, interpreted the eastern border as a fault. Alternatively, the basins could be two large, overturned, infolded synclines.

Preliminary structural work on the Bellingham conglomerate demonstrates the existence of at least two phases of deformation and most probably a third. Figure H3 is a diagrammatic sketch of the small scale structures that indicate the following structural history. The first phase of folding warped bedding (S1) around NE plunging axes (B1), with the formation of an easterly dipping axial plane schistosity (S2), a mica lineation (L1), quartz rods (L2), and stretched pebbles (L3), all parallel to the fold axes. The second phase warped the axial plane schistosity of the B1 folds in an ENE direction with the formation of a new schistosity (S3) and a "crinkly" lineation (L4) which is due to the intersection of the two schistosities. Apparently a third phase folded the first schistosity and the pebbles; it also warped the "crinkly" lineation.

Itinerary

Assemble in First National Store parking lot, 9:00 AM, Sunday, October 6, 1963, Greenville. (Greenville is about 7 miles northwest of downtown Providence along Rt. 44).

0.0 First National Parking Lot. Log begins here. Proceed west along Rt. 44.

0.9 STOP 1 - West Greenville Intersection. Park at crossroads. Georgiaville quadrangle, GQ16. Outcrop of deformed, pre-Pennsylvanian Metadiorite (?) on south side of road - note aligned plagioclase crystals. Bellingham conglomerate on north side in woods. Tight, isoclinal folds of quartz veins and a fold of bedding with axial plane cleavage - note "crinkly" lineation. Return to Rt. 44 heading east.

1.8 Turn left onto Austin Ave.

4.0 Turn right onto Mapleville Rd. and turn right again onto Colwell Rd.

4.9 STOP 2 - Brown Outing Reservation GQ16. Pass through gate and park in parking lot. Walk around reservoir to creek mouth. Folds of bedding with strong stretching and alignment of pebbles. Chevron folds of vein quartz and a quartz rod structure. Note sedimentary features. Return to Colwell Rd. heading north. Good outcrops of congl. along road.

6.7 Turn left onto Rt. 5 - proceed 0.5 miles to junction of Rt. 104 and Rt. 5.

9.9 Keep to the right on Rt. 104.

12.8 Go under bridge and turn left onto Rt. 146, west.

14.6 STOP 3 - Route 146 new road out. Intense stretching of pebbles - average of many readings - 1.0-2.5-13.5. Contact with Blackstone Series at west end of outcrop. Note strong development of "crinkly" lineation, joints and the several small diabase dikes. Exit at west end of outcrop onto Pound Hill Rd. Continue for a few hundred yards and stop on Rd.

14.9 STOP 4 - Short Stop. Walk up private road to end of outcrop - localized folds of pebbles. Continue along Pound Hill Rd.

15.4 Turn left onto Rt. 146A proceed 0.6 miles to Mendon Rd. Turn right and continue onto Rhodes Ave.

17.6 STOP 5 - Rhodes Ave. The pebbles are stretched and fractured. Note attitude of cross-bedding and the relation between bedding and schistosity. On far side of field there are localized folds of the schistosity. Continue on Rhodes Ave. to River St., turn right and cross bridge, stop below Blackstone St.

18.1 STOP 6 - Blackstone St. Marble lenses and pegmatite are present which are unusual for Bellingham conglomerate. Note again the folded schistosity with the "crinkly" lineation. End of day's logged trip.

REFERENCES

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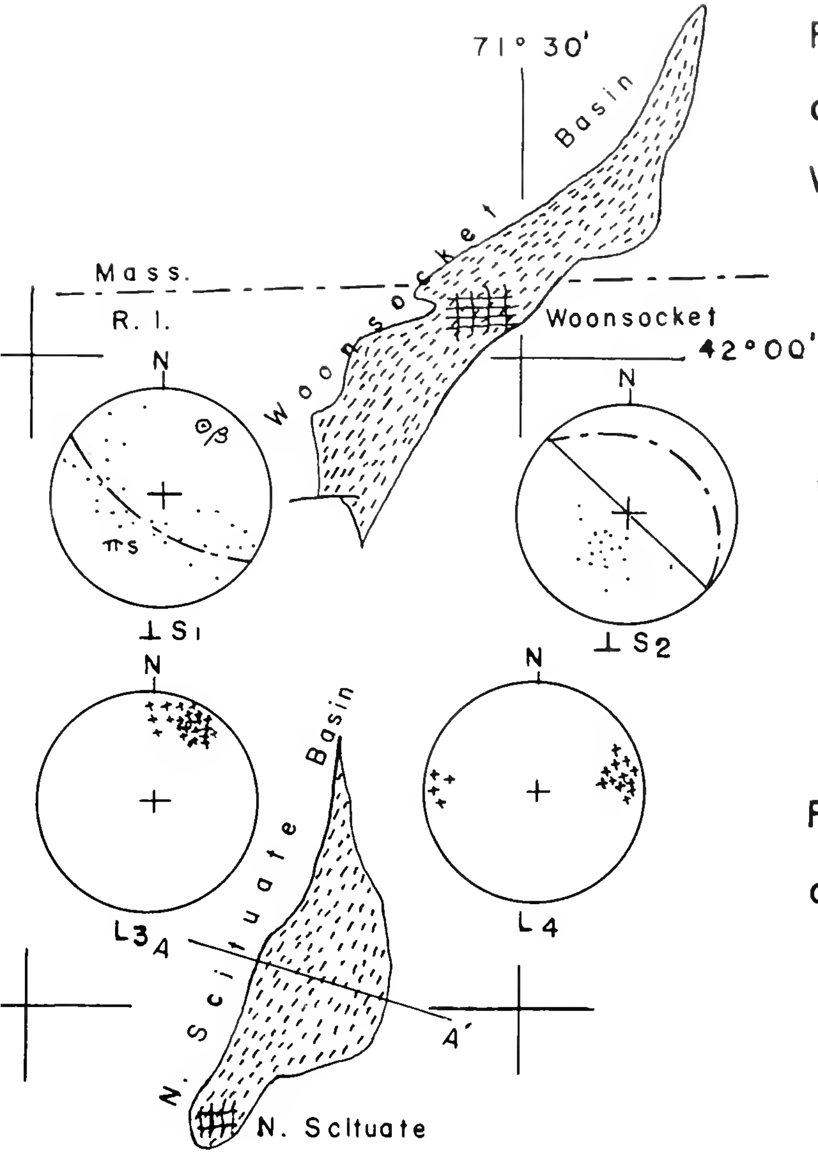
Schrader, F. C., 1896, The geology of the Woonsocket basin (abstract): Science, new ser., v. 3, p. 142-143.

Fig. – 1 Geologic sketch map of the N. Scituate and Woonsocket basins.



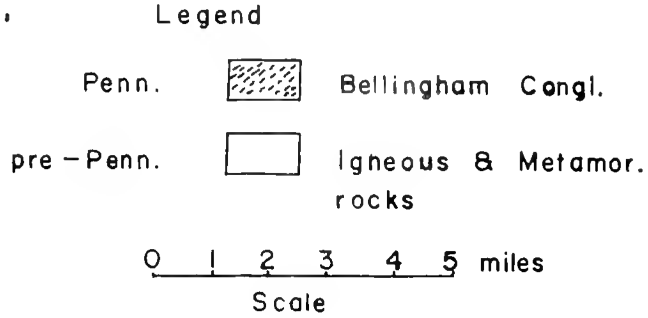


Fig. – 3 Diagrammatic sketch of small scale structures.

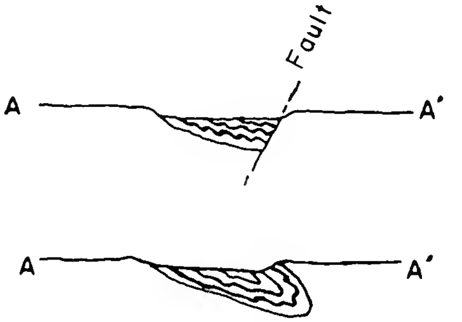
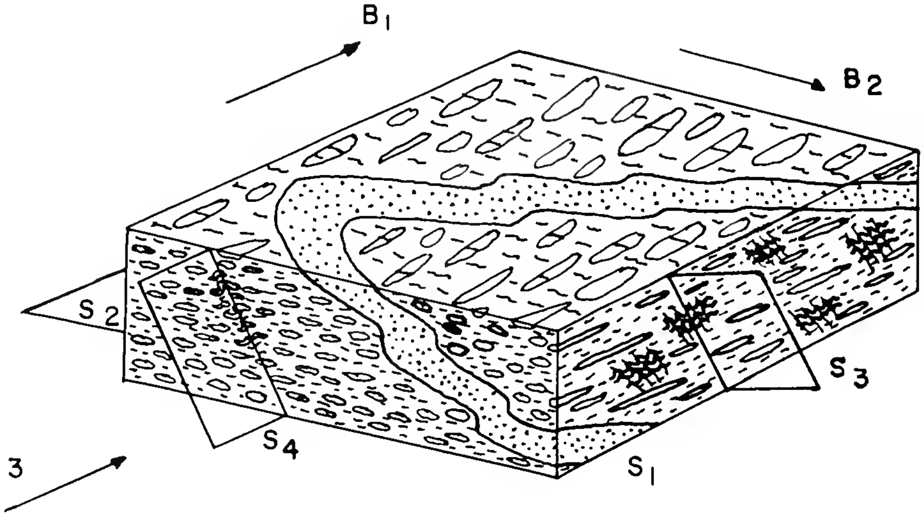


Fig. – 2 Interpretations of geologic section.



FIGURES H-1, 2, 3

Geologic structures of North Scituate and Woonsocket basins.

TRIP F

STRUCTURAL GEOLOGY, BEAVERTAIL, CONANICUT ISLAND

William M. Chapple, Brown University

Introduction

Well-developed shoreline exposures of the Pennsylvanian Rhode Island Formation exhibit a variety of structural features and provide an opportunity for studying the relations between different types of structures. Schistosity and stretched pebbles in the Rhode Island Formation were developed before the forceful intrusion of the Narragansett Pier Granite (Nichols, 1956, GQ 91), so that evidence of two periods of deformation is to be expected. Bedding and schistosity dip to the east over the whole of Conanicut Island, and it is probable that the island is located on the west limb of a major syncline (Nichols, 1956).

Itinerary

Miles

0.0 East end of Jamestown Bridge. Turn left on Beach Ave. (just beyond the Jamestown Shores Motel). Go past Nautilus St. and turn left on Spindrift St. Proceed to the foot of the hill and turn left; park under bridge.

STOP 1 - Schistose conglomerate and sandstone; garnet-staurolite schist. Bedding and schistosity are roughly parallel, and both dip 35° eastward. Conglomerate pebbles show flattening in the plane of the schistosity with the long axis of the pebbles parallel to the strike of the beds. Flattened cross-beds in some of the sandy layers make an angle of 5° with the bedding; this amount of flattening is roughly consistent with the stretching of the pebbles. Just north of the bridge a one inch thick quartz vein which cuts across the bedding is both folded and boudinaged. The folding and the boudinage are both consistent with the orientation of the flattening of the conglomerate beds, although the amount of shortening indicated by the folding is much less than that indicated by the flattening of the pebbles. Return to Rt. 138 and turn left.

0.7 Junction: turn left.

Miles

2.8 Flashing red light; church on left, Post Office on right. Proceed straight ahead.

3.4 Spit connecting Beaver Neck with Conanicut Island.

3.8 Turn right; sign to Ft. Getty. Follow road to pier, turn left, and park.

4.7 STOP 2 - Schistose conglomerate and sandstone.
Bedding and bedding schistosity are gently folded and crumpled. A few sharper folds show an axial plane cleavage, which is due to sharp flexing and some offsetting of the bedding schistosity. Farther to the southwest along the shore two styles of folding are present. (1) Sharp chevron and "half-chevron" folds with wave lengths ranging from less than an inch to a couple of feet depending on the thickness of the layers involved. These folds have approximately horizontal axes which trend N 70° W. (2) Isoclinal folds with rounded crests which plunge gently to the N 50° E. Smooth bending of bedding laminae in the competent members and an "anti-fanning" pattern of the cleavage in the incompetent beds outside fold crests indicates that these folds are of flexural origin. Return to Beavertail Road.

5.6 Beavertail Road; turn right.

8.2 Beavertail Lighthouse.

STOP 3 - Fine-grained garnetiferous phyllite with some thin quartzite beds. Cleavage in the phyllite is due to alignment of platy minerals and elongation of quartz grains. Sandstone beds are folded and some are boudinaged and brecciated. A normal fault striking N 70° E and dipping 60° to the northwest passes under the bronze plaque. Half a mile north the fault offsets a minette dike; the offset and vertical slickensides indicate vertical movement of about 30 feet (Nichols, 1956). Return northward on Beavertail Road.

8.6 Microwave tower: turn left, park, and walk to shoreline outcrops.

STOP 4 - Fine-grained phyllite with thin quartzite beds. Well-developed "kink bands" which offset the schistosity are present. Folds of quartzite layers in the phyllite illustrate the relationship of the cleavage to the folding.

REFERENCE

Nichols, D. R., 1956, Bedrock geology of the Narragansett Pier quadrangle, R. I.: U. S. Geological Survey, Geol. Quad. Map GQ-91.